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PAPERS ON

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THE RED RING OR 'ROOT' DISEASE OF COCO-NUT PALMS.

BY WILLIAM NOWELL, D.I.C.,

Mycologist on the Staff of the Imperial Department of Agriculture for the West Indies.

An affection previously known as the Trinidad root disease, but which it is now proposed to distinguish as red ring disease, is responsible for the loss of many coco nut palms in Trinidad, Tobago, and Grenada. In the great majority of cases the trees die soon after reaching maturity, during the bearing of the first few bunches of nuts, but instances have been verified of the death of trees not less than twenty years old.

Some confusion has existed between this disease and infectious bud-rot, owing to the fact that putrefaction of the soft tissues of the enclosed central shoot is exceedingly liable to accompany the death of the coco-nut palm, whether this arises from mechanical injury, from chemical poisoning, or, as in the disease in question, from the presence of parasites.

The attraction of the palm weevil (*Rhynchophorus palmarum*) to the fermenting tissues has sometimes given rise to the belief that this beetle was involved in the origination of the failure.

When trees which are obviously failing, but have not reached the final stages, (Pls. I and IV) are cut down and examined, there is, in most cases, no trace whatever of bud-rot or of weevil injury, while infestation with the parasite hereafter described is already general and severe.

From an early stage in its investigation the most definite distinguishing feature of the disease has been recognized to be the existence in the stem of a well-marked zone, usually 1-1½ inches wide and beginning 1-2 inches from the periphery, in which the ground tissue is dull red, or red mingled with yellow. This zone is best developed in the basal half of the stem. It is generally referred to as the red ring, from its appearance as such in a cross section of the stem. (Pl. III.)

History.

Mr. J. H. Hart, (1) Superintendent of the Royal Botanic Gardens, Trinidad, in 1905 had his attention called to a coco-nut disease prevalent at Cedros on the western coast of the island. He reported that a typical example showed infection from the ground upwards, and had a ring of red discolouration lying inside the woody exterior of the stem. His observations led to the conclusion that there had been a succession of losses of the same kind for many years.

As an outcome of Hart's report, Mr. F. A. Stockdale, (2, 3) Mycologist on the Staff of the Imperial Department of Agriculture, was assigned to the investigation of coco-nut diseases in Trinidad, and visited the island for that purpose from July 10 to August 14, 1906. In a lengthy report Stockdale distinguished between root disease and specific bud-rot, and recognized the tendency of the bud to putrefy in the case of trees dying from any cause. He described the symptoms of root disease with a fullness that leaves no room for doubt as to its identity with the present affection. He observed the fruiting of a *Botryodiplodia* to be general near the base of failing leaves, and assumed that fungus hyphae found in the affected roots pertained to the same species. He came to the conclusion that the fungus was the immediate cause of the disease, that this began with an infestation of the roots, that the red zone in the stem was an effect of the stoppage of the water-supply, and that a secondary infestation of the leaf bases followed.

In 1907 Mr. O. W. Barrett, (4) U. S. Department of Agriculture, reported that about 95 per cent. of coco-nut losses in Trinidad were due to root disease, and that only a few cases of bud-rot occurred.

Mr. J. R. Johnston, (5) Assistant Pathologist, U.S. Department of Agriculture, visited Trinidad during his investigation of the bud-rot disease, and recorded his conclusions in a short paper issued in 1910. After reviewing the work of previous investigators he dismissed Stockdale's root disease as non-existent, and stated his opinion that the only destructive disease of the coco-nut occurring in Trinidad was identical with bud-rot as generally understood. The putrefaction of the bud which Stockdale repored as accompanying the death of the tree from root disease was regarded by Johnston as evidence that the disease was bud-rot and nothing else. He denied that such putrefaction was a natural sequence of death from any other cause.

Mr. J. B. Rorer, (6) Mycologist to the Board of Agriculture, Trinidad published in 1911 his conclusions from studies of coco-nut diseases extending over a period of two years. He fully

confirmed Stockdale's conclusions as to the existence and severity of root disease as distinct from bud-rot, but pointed out that Stockdale's assumption that it was caused by *Botryodiplodia*, or by any fungus, was unsupported by evidence of even the slightest value. Rorer made an extensive mycological examination of material from diseased trees, and gives the following account of the results of 194 tube cultures :—

Cultures have also been made from all parts of the diseased trees both by the poured plate method and by cutting out small bits of the affected tissue under aseptic conditions and putting them on sterilized potato cylinders or agar in tubes. In all, 194 tube cultures have been made from diseased trees from Cedros, the East Coast, and Tobago, and the results have been uniformly the same. In cases in which cultures have been made from portions of the root which showed only slight discoloration, or in other words, the first signs of disease, no growth of any kind has taken place, except occasionally where contamination evidently took place from the air. This supports the results of the microscopical examination that there is no fungus in such roots. When the cultures were made from the more discoloured root tissues the results were very variable. About one-half the tubes remained sterile, showing that there was no fungus in the bit of tissue used, while the others gave a variety of things, generally mixed cultures of fungi and bacteria. No one fungus was found constantly in the cultures, and in no case, except where very rotten and black roots were used, was Diplodia obtained. The commonest fungus which was found was a species of Fusarium.

Rorer sums up as follows :—

Finally, the work of the past two years shows rather conclusively that it is not due to a Diplodia or to any fungus parasite, in fact all the observations point to the conclusion that it is a physiological trouble resulting from unfavourable conditions in the soil. Whether it is the lack of some element necessary to the continued growth of the coco-nut tree, whether it is the presence of some substance which is toxic to coco-nut roots, or whether it is due to acidity or lack of aeration in heavy soils it is difficult to say. It is very noticeable, however, that the disease is only found to any considerable extent in places where the trees are planted on land which is not good coco-nut soil, or in places where the trees have received no cultivation whatever. Another point worthy of note is that the disease is frequently met with on old sugar land.

The present writer ([8]) first saw the disease during a ten days visit to Grenada in 1918, made in consequence of a report from Mr. J. C. Moore, Superintendent of Agriculture, that losses were becoming increasingly frequent among the considerable number of coco-nut trees planted during the previous five to ten years. During a visit to Trinidad ([9]) made in connexion with sugar cane diseases, and extending from December to February 1919, occasional opportunities arose of making observations on the disease. In February of this year another week was spent in Grenada in its investigation.

Sufficient information has been obtained for a description of the disease as it appears when fully developed, and for the announcement of its invariable and close association, in all cases examined, with a nematode worm which the writer believes to be its cause. The mode of infection and the early course of the development of the disease remain for investigation, but, as the writer is going on leave for some months, he has considered it advisable to put forward an account of the results so far obtained.

Distribution and Incidence.

Reference has been made to Hart's conclusion that the disease had been present at Cedros for an indefinite but lengthy period previous to 1905. It is at the present time very widely distributed in Trinidad, and has caused heavy losses in Tobago. There is no record of its occurrence in Grenada previous to about 1916, when deaths now attributed to this cause began on the Westerhall plot. The rather general movement towards coco nut planting which was made a few years ago in Grenada has been ollowed by the occurrence of the disease in various quarters, fncluding the northern and southern extremities of the island.

i There is no record of the presence of the disease elsewhere than in the islands mentioned. It may very well occur in South America without having been reported, but does not appear to be present, so far as recent experience shows, in the islands of the Lesser Antilles north of Grenada.

Definite information regarding the number of trees destroyed by the disease is scanty. The extent of liability to loss at any one time depends in the first place on the number of trees passing through the critical period, which extends from the fourth to the seventh year. For this period the death-rate may extend to 30 per cent., which is the owner's estimate in respect of an extensive young plantation in one of the islands. In the government plot at Westerhall, Grenada, now six to seven years old, out of sixty trees, grown under favourable conditions, eighteen have been lost from 1916 onwards; at the present time, from outward appearance and from borings made in the stem of each tree, no further cases can be detected. This would give a loss during the critical age of 30 per cent. in this case also, the seriousness of which appears when it is remembered that it means the loss of about five years' cost of cultivation and the deferring of returns for at least a second five years, with prospects of repetition of the loss through reinfection of the plants used to supply vacancies.

After the critical age is passed losses from the disease very rapidly diminish, but cases occurring up to ten years are not particularly rare, and, as previously mentioned, odd cases have been verified in trees over twenty years old.

So far as the writer knows, the only occurrence of the affection in other palms which has to be recorded is one which was verified during his most recent visit to Grenada, when a specimen of an unlabelled species of Cocos in the Botanic Gardens, with a stem measuring 29 feet, died with all the usual symptoms of the disease, and with full nematode infestation of roots, red ring, and petioles.

External Symptoms.

Descriptions of the visible process of failure have been given by Stockdale and Rorer, and with these the observations of the writer agree. The salient features are as follows:—

(a) Progressive yellowing and browning of the leaves take place from below upwards, commencing at the tip of each leaf reached in the process. Commonly the lowest living leaves are

the first affected, but occasionally one or several of these may remain green while the discoloration, commencing above them, successively involves the younger leaves. In its early stages the process is indistinguishable by external appearances from the natural dying-off of the old leaves, especially where this is accelerated by drought, water-logging, or poor conditions of growth in general. The difference becomes apparent, however, from the steady march of the discoloration, which soon begins to involve leaves in full vigour, and continues to those in which the leaflets are not even fully expanded. The process is relatively rapid. The Grenada tree in Plate I, which when photographed on February 22 was exceedingly conspicuous from its rich colouring of brown, orange, and yellow, involving all but the central tuft of leaves, attracted no attention in early January when the plot was visited by the Superintendent of Agriculture for the purpose of detecting diseased trees.

(b) The shedding of green nuts of all sizes present takes place concurrently with or slightly in advance of the discoloration of the leaves, and is thus in some cases the first external sign of trouble. Associated with this symptom is the shedding of open and unopened flowers, and partial withering of the branches of the inflorescence, extending finally even to the contents of the still unopened spathes. In this connexion it must be remembered that shedding of small nuts often occurs in healthy trees.

As secondary symptoms there occur :—

(c) Development of patches of brown or black rot, wet but firm, on the expanded leaf bases, and sometimes of similar patches on the leaf-stalk higher up. This appears to be the chief reason for the tendency for one to several of the leaves of affected trees to break, often at one to 2 feet from their insertion, and hang down. The patches here referred to seem invariably to develop crowded pustules of *Diplodia* sp. (which may equally well be designated *Botryodiplodia*), presumably corresponding to Stockdale's fungus. A comparable infestation of the failing branches of many trees, notably of cacao and lime, with *Diplodia* spp. is frequent and well-known in these islands ; the status of *Diplodia* being now generally admitted to be mainly that of a saprophyte, with powers of parasitism limited in most cases (the exceptions being usually fruits) to the invasion of tissues with less than normal vigour. Such infestations are common if not general in healthy coco-nut palms on leaves approaching senility. The extension of a similar failing condition to younger leaves in the trees affected with red ring disease seems quite adequate to account for the association of Diplodia rot with that affection. The existence of nematode infestation in these leaves long before the fungus reaches them will be described below.

(d) In cases allowed to reach the final stages there ensues a putrefaction of the soft tissues forming the apex of the stem and the base of the central column of unexpanded leaves, as also of the similar tissue at the base of the young inflorescence. In each case this involves tissue deeply enclosed by the sheathing bases of the leaves (Pl. IV). The experience of the writer supports Stockdale's opinion that putrefaction of the region of

the bud is a normal sequence of any injury sufficient to bring about the death of the tree. There is no sound basis for the assumption that any necessary connexion exists between this mode of decay and infectious bud-rot disease. (The occurrence of bacterial putrefaction and a bad smell applies equally to the heart of a rotting cabbage.) The writer has previously recorded [7] the case of a perfectly healthy coco-nut palm in Barbados (where no bud-rot occurs) poisoned by inserting sodium arsenite at the base of the stem, in which complete putrefaction of the bud occurred within two weeks. Recently the top of another healthy tree was cut off with an axe, with a similar result ensuing in six days.

Johnston's contention that bud-rot is the cause of death in the Trinidad disease could, one thinks, never be made or upheld after examination of any typical case such as those shown in Plates I and IV, in which trees known from experience to be near inevitable death show no trace whatever of bud-rot, and in which, in fact, the central tuft enclosing the bud is the only part of the foliage preserving a completely healthy appearance.

Internal Symptoms.

The description of the internal symptoms of affected trees which follows refers to the stage of development of the disease in trees which have reached the condition of those illustrated in Plate I, in which the tree still retains its normal shape, but only the central tuft of partly expanded leaves is still a healthy green, while the remaining leaves show various stages of ill-health from merely yellow tips to complete yellow and brown discoloration. The succeeding stages of failure are gone through rapidly, and are usually dominated by the secondary symptoms already described.

The Stem.—The usual distribution of the red zone in the stem at this time is seen in the vertical section of a standing tree shown in Pl. IV. The zone completely surrounds the base of the stem, extends upwards as a solid band of reddened tissue for about 4 feet, then breaks up into longitudinal streaks and finally into scattered dots about 1 millimetre in diameter. In the latter form it extends to the soft meristem underlying the bud, in which region the dots appear to be generally dispersed below the flattened apex of the stem.

All the cases seen by the writer have had the red ring in the situation described, but Stockdale records that when failure of the leaves has begun higher than usual, so as to leave a ring of the lowest leaves unaffected, the discoloration of the stem is found towards the centre. Rorer figures a similar instance, reproduced here in Pl. II, Fig. 2.

The Leaves.—When the leaves of a tree in the stage now under description are removed one by one and split open in the median line, a similar homogeneous red, red-spotted, or red and yellow-streaked and mottled discoloration is revealed in the leaf-stalk, extending in the fully developed leaves from the base to a distance of from 6 inches to 2½ feet outwards. In the older leaves it becomes wholly or partly masked by the development of brown rot, or by the natural browning of the tissues. Parts of four mature leaves

from the tree in Pl. I are shown in Pl. III, Fig. 1. The first piece from the left shows brown rot at its extremities, with red mottling between. The second is a healthy green leaf which was the only one below the point from which the leaves began to fail. The third shows deep red mottling with brown rot above, and the fourth, mottling without brown rot.

When the compact upright column formed by the leaves not yet bent outwards from their base is examined, the red discoloration of the petioles continues, often with great intensity, although the leaves themselves, as the centre is approached, are healthy in appearance, or but slightly tinted yellow at the tip. The first four leaves seen in section in Pl. IV., beginning on the right, were infested from the base, in order of age, for 12, 9, 6, and 6 inches, respectively. The fifth showed only scattered pink spots and lines, and the remaining young leaves were sound. In two other cases examined at the same time, the tree in Pl. I and another similar to it, bright red and yellow discoloration occurred, with decreasing extent and intensity, in the soft white tissue of each still younger leaf so far as these could be distinguished. (cf. Pl. VIII. Fig. 1).

It is a notable fact, and may prove to be significant, that, in the examples closely followed out, the area of discoloration tended in the younger leaves to recede from the base, retaining at first a narrow connexion on the dorsal side, then leaving it altogether. In the record made of a very young, still enclosed leaf, for example, the basal 9 inches was perfectly white soft tissue, then from the point of attachment of the first leaflets there was an enclosed central infestation shown by vivid red and yellow spots and extending for 2½ feet.

The Roots.—The effect of the disease on the tissues of the roots is confined to the cortex, which consists of radial lamellæ loosely packed into the region between the horny hypoderm and the central woody strand. This tissue is pure white and soft when healthy, but when affected by the disease under consideration it becomes dry and flaky and passes through stages of discoloration from white to light yellow or pink, then to dark yellow or reddish brown. Affection of this nature in the root may extend for any distance from an inch or two to 10 or 12 feet from the point of attachment. In all cases examined by the writer it has been continuous, and decreasing in intensity outward from the base of the tree. In some cases all the roots examined have been discoloured for several feet; in others the range of variation given above has been found in the roots of one tree, while in the tree mentioned above as having its leaves infested to the centre, only two or three roots were found discoloured, and these only for an inch or two, although the tree was dug out and a thorough examination made.

The Association of Nematodes with the Disease.

Examination of stained sections of a large amount of material from all sources confirms Rorer's conclusion as to the absence of any causative relation between fungi and the disease. Hyphae have been found to be rarely present in the diseased living roots, and never until the degree of discoloration has

reached an advanced stage. They have not been found in the discoloured tissues of the stem nor in the very definite lesions existing, without visible connexion with the surface, in the petioles of the young leaves.

On the other hand, there is a perfectly constant association of nematode worms with the lesions existing in stem, leaves, and roots; an association which begins with the first trace of discoloration, and persists until the infested tissue is dead and decayed. The scattered red dots in otherwise sound living tissue, which mark the upward extension of the red zone in the stem and the beginning of infestation in the leaf-stalks, are initial nests containing usually a few adult worms together with immature specimens and eggs. The red zone in the stem is, in its every part, simply a vast infestation with myriads of active worms.

In sections of the tender white meristem of the upper extremity of the stem and of the embryonic leaves, the worms may be seen in large numbers, threaded along between the cells like fungus hyphae, or lying coiled up in one of the larger intercellular spaces. In these situations they are by no means confined to the discoloured spots, but appear to be able to travel in any direction through the living tissue.

In the roots the worms are present in large numbers, closely and invariably associated with the typical discoloration. It is remarkable that in no case have eggs or young worms been seen in the hundreds of examinations made of the root tissues. The great breeding ground is the red zone in the stem, and judging by the relative abundance of eggs, reproduction appears to be most active in its upper less-developed sections.

The infestation is in all cases confined to the ground tissue, the vascular bundles remaining to all appearance unaffected in any way.

The restriction of infestation in the stem to a narrow zone, and the definite location of this zone in each individual case cannot at present be satisfactorily explained. Attempts to connect it with the anatomy or functions of the stem have not succeeded. It is now conjectured to be the resultant of infestation near the growing point and the subsequent expansion of the stem.

In mature stems examined the following structure has been made out. There is first a fibrous zone some ½-inch thick corresponding in position with the bark of a dicotyledonous tree. The main body of the stem beneath this is divisible into three concentric regions marked by the opposed directions of the spiral course of the vascular bundles. There is (a) an outer zone, not usually more than an inch thick above the swollen base, in which these are thickly massed and nearly vertical, then (b) a middle zone up to 2 inches wide with a decided spiral ascending to the right or to the left, and then (c) a wide core, 5 inches and upwards in diameter, with more scattered bundles directed to the left or right respectively. Differences in diameter of the stem mainly affect the last mentioned region. In Pl. V the spots are in the outer zone, while the solid discoloration coincides with the first inch of the middle zone, but leaves the

remaining ¾-inch of the same quite unaffected. The main leaf traces pass across the infested zone without influence upon it.

In all the cases seen by the writer the ring has occupied about the position indicated above, but as already mentioned, both Stockdale and Rorer mention cases where the location has been more central.

The Evidence of Causation.—The theory that the nematode in question is the cause of the disease rests upon the observations detailed above, which amount to this: that the worms are closely and invariably associated from its initial stage with each of the primary symptoms developed, while the symptoms classed as secondary are common to coco-nut palms failing from any cause. It would in fact appear to be the most accurate expression of the case to say that infestation with nematodes constitutes the disease, its essential anatomical characters being to all appearance the direct result of the presence of the worms.

Attempts are being made to produce the affection artificially by introducing infested material into roots and stems, but these have not proceeded long enough for results to be looked for.

Careful search for comparable nematode infestation of material from trees failing from other affections has proved entirely negative.

Influence of External Conditions.—Cases of the disease have been examined by the writer in all gradations of soil from beach sand to exceedingly stiff clay. No influence on liability to the disease has been detected as proceeding from these variations, or from any unfavourable conditions of growth. The greater number of the examples seen have been in vigorous well-grown trees, and the finest young tree the writer has ever seen, which was growing in deep rich mould where the roots had access to running water, was infested.

A large number of cases were recently seen occurring in a new plantation made seven to eight years ago on virgin soil newly cleared from forest. Most of these were in trees growing under conditions which must be regarded as excellent from every point of view. Rorer's observation as to the tendency of the disease to appear on old sugar land had obviously no application in this and in some other instances seen, except so far that the possibility of nursery infection has not been excluded by the evidence so far collected.

The Origin and Cause of Infestation.—The application of measures adequate for the prevention of the disease requires that the time and manner of infection should be known. The distribution of the infestation in a fully affected tree may be made the basis of reasoning in which certain fairly definite conclusions may be reached, but the validity of these results needs confirmation from the study of cases in the early stages of development, and these have not yet been seen. The disease has previously been regarded as primarily affecting the roots. This view is disposed of by the facts (a) that in all observed instances the infestation of the roots proceeds outwards, (b) that no breeding of the worms takes place there, and (c) that examples are met with of otherwise fully infested trees in which no roots can be found to be affected.

This evidence does not exclude the possibility of infection taking place through one or a few roots which later decay or otherwise escape detection, but there is at present nothing to show that such is the fact.

Analysis of typical cases such as are illustrated in the accompanying plates leads to the following considerations. The red zone in the stem is the base of the infestation, regarded in relation to the invasion of the roots and leaf-stalks The location of the zone has no apparent relation to the anatomy or, so far as is known, to the physiology of the mature stem, and once formed the zone is capable of no lateral expansion, but only of intensification. It is completely developed in that section of the stem which has taken on its permanent form, and becomes less and less complete in density, but for a considerable distance not notably in width, in the upper and still plastic section. It would appear that it is laid down by extension at its upper extremity, as the stem itself is laid down, and matures as the section of the stem it occupies matures. This idea is supported by the known ability of the worms to move freely in the unhardened tissues of the upper stem, and their apparent inability, as evidenced by the continued limitation of the older parts of the infested zone, to occupy fresh territory in developed tissue. It may for the present be assumed that a knowledge of the regional development of the uppermost section of the stem would explain the position occupied by the zone in the fully formed and hardened sections.

From this theory as to the development of the infestation, if it were established there would follow a very important conclusion, namely that infection in all the cases so far seen, since in these the red zone has commenced from the base of the tree, must have taken place at a very early stage, before any part of the stem had so far matured as to prevent infestation.

This immediately suggests the question whether, in fields established according to the usual practice, infection may be regarded as originating from and being confined to the nursery. The sporadic distribution of the early cases, and the frequency of their occurrence on land with no previous record of coco nut cultivation lend some colour to the idea that they are most likely to have originated in the nursery, but the general tendency for the development of the first cases into well-marked groups affords strong evidence of the spread of infection after the trees are planted out. The group of trees Nos. 45-57, with 39 and 53, shown with the dates of failure on the reproduced plan of the Westerhall Plot, affords an illustration of this.

Allowing that infestation begins at an early age and must therefore continue in most cases several, and in some cases many, years, the further question arises as to what development brings about the death of the tree. The infestation of a narrow zone of the cortex of the stem would not appear to involve fatal results, and the injury to the cortex of the roots, while it looks more serious, is not always present when the final and typical symptoms are developed. These begin, outwardly, with the progressive failure of the leaves, and this failure is accompanied by infestation of the leaf-stalks. It is significant that one or

more of the lowest green leaves may escape this infestation and remain healthy in appearance after numerous younger leaves have failed. There is a strong presumption in these cases, which is supported by such examinations as have been made, that the still older leaves, which have reached senility and been shed, were also free from infestation. The conclusion is indicated that invasion of the leaf-stalks marks the entry of the disease to its final stage, and it may, as it develops, be the actual cause of death, but what determines this invasion is not at present clear.

The infestation of the leaf-stalks, it has already been pointed out, begins commonly while they are young and tender and occupy the apex of the stem, and no evidence has been obtained, in the way of visible connexions, that the worms can pass outward from the red zone into the bases of older expanded leaves. Such a connexion can also be absent, over a distance which in one case extended to 9 inches, between the visible seat of infestation in a very young leaf and the apex of the stem to which it is attached. In this case rapid elongation is more likely to have caused the separation, the tissues are in a condition to be easily traversed by the worms, and the possibility is not excluded of their passage between the closely rolled elements of the shoot and subsequent entry into the tissues higher up.

The Control of the Disease.

There is a regrettable amount of deduction in the basis of the only counsel as to control which can be given at this stage of the investigation.

There is no record of the recovery of any tree which has shown the outward signs of the disease, nor does there seem any possibility of the successful treatment of a tree once it becomes infested. Prevention, on the other hand, may prove to be feasible.

Of the manner in which the infection is conveyed nothing is at present known. The red ring in two decaying stumps from which the tops had died four to five months before was found to contain very large numbers of the worms in a quiescent but living condition. It is reasonable to assume, in view of the habits of plant nematodes in general, that the soil in the neighbourhood of the diseased trees becomes infested and remains so for a considerable period.

It is conceivable, and sufficiently probable to be the basis of precaution until the facts are known, that the worms may be harboured in the crevices of the fibre of fallen nuts and thus be in a position to enter the young plant after germination. It would therefore be safer to plant nuts that come from areas with no record of infestation, or to use them only when picked from the trees and not gathered from the ground.

Enquiries are being made and information would be welcomed regarding the occurrence or non-occurrence of the disease in fields planted at stake, a point which may have considerable importance.

The Prevention of Field Infections.

If would appear that the entrance of the parasite must be made either by way of a root or between the bases of the young leaves, and of the two methods the latter seems the more likely. For the protection of young trees for the first two or three years after setting out, the writer intends to experiment, when opportunity affords, along three lines :—

(a) Dusting : with powdered sulphur and with mixtures of sulphur with 2 per cent. lead arsenate, and of sulphur with lime.

(b) Spraying : with Bordeaux-nicotine sulphate and Bordeaux-lead arsenate ; with whale-oil soap solution, and with lime-sulphur solution.

(c) The fixing of a slowly soluble or diffusible solid in such a position that rain will wash it down between the younger leaves.

Selection among these measures for extended trials would be made in the first instance on the basis of cheapness, as determined by first cost and persistence. In view of the exposure of new surfaces by the expansion of the leaves, and of the presumed dependence of the migrating worms on moisture supplied by rain, the third method seems the most promising. Trial with soaps and salts used in this manner is suggested to those who wish to experiment.

If, as believed, the trees which ultimately die are previously infested for several years, there is an obvious advantage to be gained by their early detection. With this consideration in view the remaining trees on the Westerhall Plot were tested for the red ring by making a boring near the base of each stem. The results in these cases were negative, but tests on known infested trees appeared to substantiate the feasibility of the method The holes were made with a diameter of ¾-inch and a depth of about 2½ inches by means of a brace and bit, and were closed with tarred plugs of deal Until the after effect of these wounds is seen such trials should be made cautiously, or on the understanding that they are at 'owner's risk.' In making a diagnosis from the extracted chips care must be taken not to mistake for infected tissue the embryonic roots just below the outer fibrous layer (cf. Pl. 5, Fig. 2) which redden very quickly on exposure. A glass slip, a drop of water, and a pocket lens with a magnifying power of 15 or 20 enable the worms to be readily seen and he possibility of mistakes to be eliminated.

The Problem of Infested Trees.

Faced with the disposal of a well-grown palm infested in stem, roots, and leaf-stalks with millions of active worms, the planter has no easy task ; when the number of trees to be disposed of reaches twenty-nine in one week with 100 more waiting, which were the current figures on one estate visited, adequate destruction becomes a practical impossibility. Accepting, however reluctantly, the certainty that the trees under such circumstances will not be destroyed, consideration has to be given to the consequences. On the theory already stated, that infection

takes place only at an early age, the matter is not so serious as it looks, since in a regular field the surrounding trees are too mature for infection by the time the disease is manifested.

On the other hand, if the method suggested above, or any other, can be successfully applied to the discovery of the infestation in its early stages, the complete destruction of any trees so found is important, with a view to preventing the formation of the usual groups of secondary infections.

Summary.

The red ring disease of coco-nut palms (see Introduction) is inferred to be of long duration, and to begin in the first two or three years of the tree's existence.

Outward symptoms of its presence appear only in connexion with the death of the tree, the process of which occupies only a few weeks. These symptoms consist of the dropping of nuts and the progressive discoloration and failure of the leaves, beginning usually, but not invariably, with the oldest leaves, and always progressing towards the centre of the shoot.

Trees which are dying of the disease are invariably infested with a nematode worm, which occupies and breeds in a zone of the stem (the red ring), infests the petioles of the leaves, including those still enclosed in the central shoot, for a distance varying from a few inches to 2 or 3 feet, and is found associated with a discoloured condition of the roots. The red zone is best developed at the base of the stem and diminishes in intensity towards the apex, where it is represented by scattered red dots containing nematodes and their eggs.

The manner of infection and the course of the infestation are not known further than they may be inferred from fully developed examples. It appears certain from the grouping of cases in the field that the disease can be communicated from infested plants to their neighbours.

Present advice is to avoid planting nuts which have lain on the ground in the neighbourhood of infested trees or previous sites of such, and to destroy promptly and as completely as possible infested trees, especially the early cases. The need is pointed out and suggestions are made, for: (a) means of early detection of infested trees, (b) means of protection for young trees in the field.

Note.—With reference to the zones in the stem described on p. 196, it has been found that in some of the trees examined the leaf-spiral ascends to the right, and in others to the left. The direction of the spiral of the vascular bundles in the outer zone of the stem corresponds to that of the leaves. The direction of the second zone of fibres is reversed, and the central core repeats the direction of the leaves.

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Note on Artificial Infestation.

From Grenada, Mr. J. C. Moore, Superintendent of Agriculture, reports under date September 19, 1919, that trees Nos. 11, 13 and 15, into each of which a fragment of red ring material was introduced by means of an auger hole in the stem during my visit last February, were examined sixty days later and found to be heavily infested with nematodes, with a pronounced red ring from base to apex, and other usual external and internal symptoms. Nos. 12, 14 and 16 in the same row, similarly bored, without introduction of diseased material, survive.

Later infection experiments by Mr. Moore comprised the dropping in the axils of Nos. 23, 24 and 36 of pieces of infested tissue, no wound being made. Of these trees Nos. 23 and 24 have already been found to be in an infested condition. Further, Nos. 59 and 64 were inoculated by cutting out a cube from a petiole, introducing a small amount of infested material and replacing the cube. Of these No. 64 has been examined, and an infestation of numerous leaves and scattered red spots in the trunk found. One of the other trees shown in the plan, No. 37, has died spontaneously from the disease.—W. N.

Correction.—In the legend of Plate V, Fig 1, 'Plate II, should read 'Plate III.'

Fig. 1. TREE 66, WESTERHALL.
Discoloured and about to die.

Fig. 2. A TRINIDAD EXAMPLE.
Somewhat more advanced.
(Loaned by Board of Agriculture, Trinidad.)

PLATE I.

Fig. 1. RED RING IN STEM OF TREE IN PLATE I, FIG. 2.
(Loaned by Board of Agriculture, Trinidad.)

Fig. 2. A STEM WITH CENTRAL DISCOLOURATION.
(Loaned by Board of Agriculture, Trinidad.)

Fig. 3. FINAL STAGE OF FAILURE, WITH PUTRESCENCE OF THE BUD.
(Loaned by Board of Agriculture, Trinidad.)

PLATE II.

PLATE III.

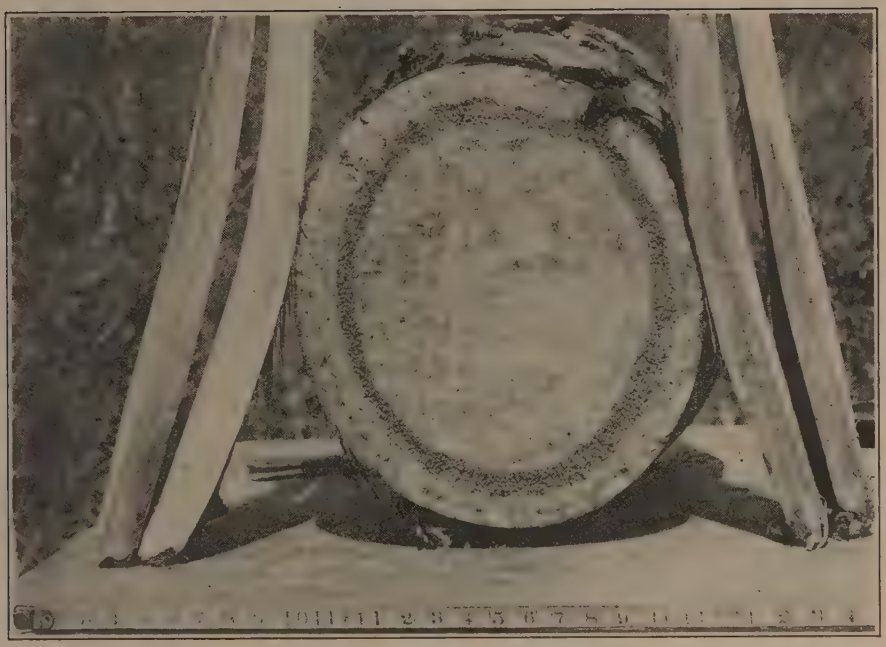


Fig. 1. SECTION OF TREE 66;
Three infested leafstalks and one (the lowest) sound.

Fig. 2. SECTIONS OF TREE 66 AT 1 FT. 9 IN. AND 3 FT. 6 IN.
Trace of red ring on left of upper section.

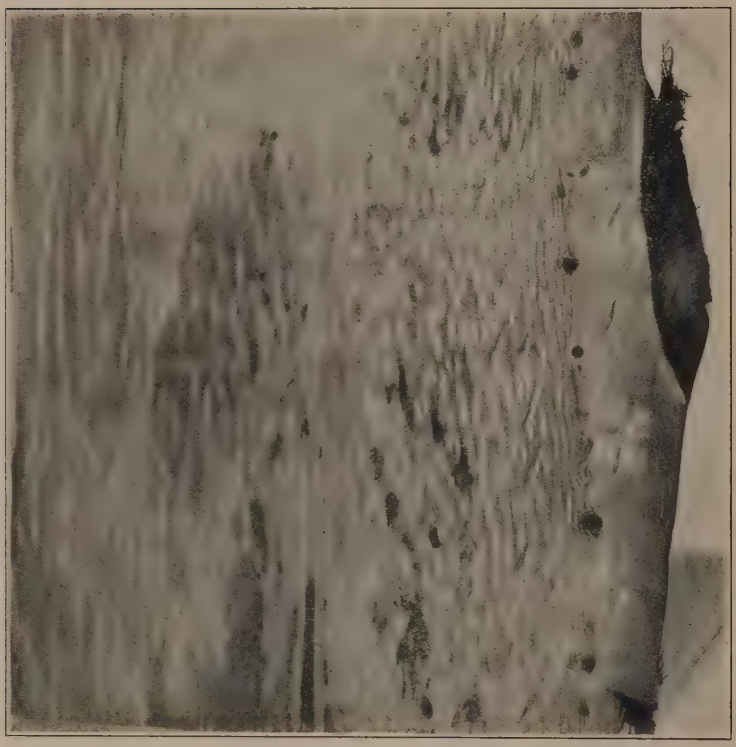
PLATE IV.

MEDIAN SECTION OF TREE 62.
Red ring distinct to about 6 ft.; remaining 2 ft. red dotted.

Fig. 1. PART OF LOWER SECTION IN PLATE II, FIG. 2, NATURAL SIZE.

Fig. 2. LONGITUDINAL SECTION OF SEGMENT IN FIG. 1, NATURAL SIZE.

PLATE VI.



LONGITUDINAL SECTION NEAR UPWARD TERMINATION OF RED RING.
(PLATE III, FIG. 2.)

(The line of dormant roots immediately below outer fibrous layer, seen in all the sections, is not infested.)

PLATE VII.

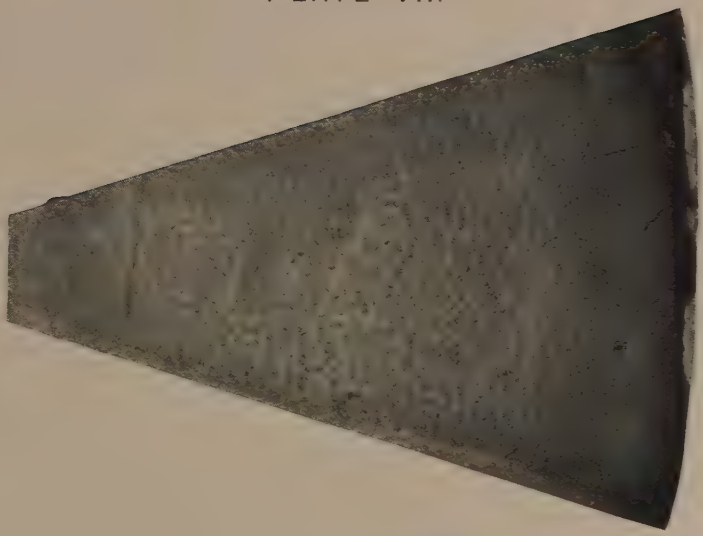


Fig. 1. UPPER SURFACE OF SEGMENT IN PLATE VI.
A few red dots between the vascular bundles.

Fig. 2. LOWER SURFACE OF SEGMENT IN PLATE VI.

PLATE VIII.

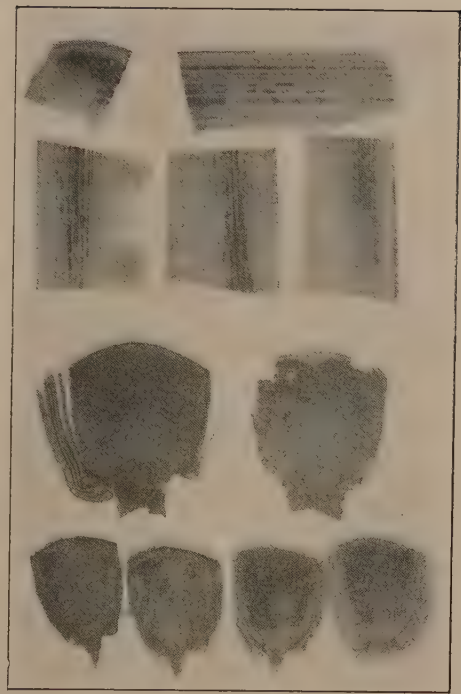


Fig. 1. INFESTATION OF A VERY YOUNG LEAF (ABOVE) AND OF A YOUNG UNEXPANDED LEAF (BELOW.)
(Natural Size.)

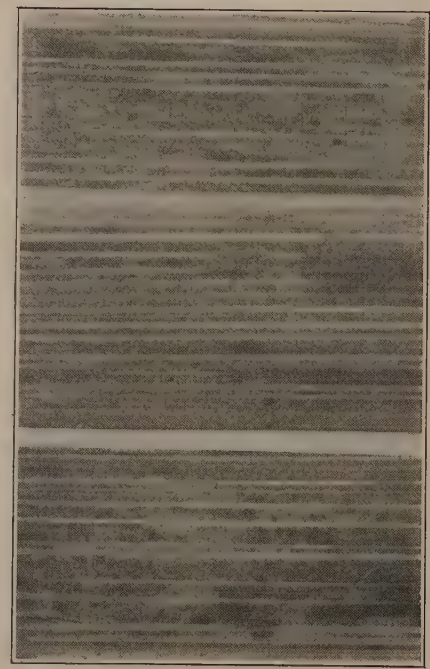
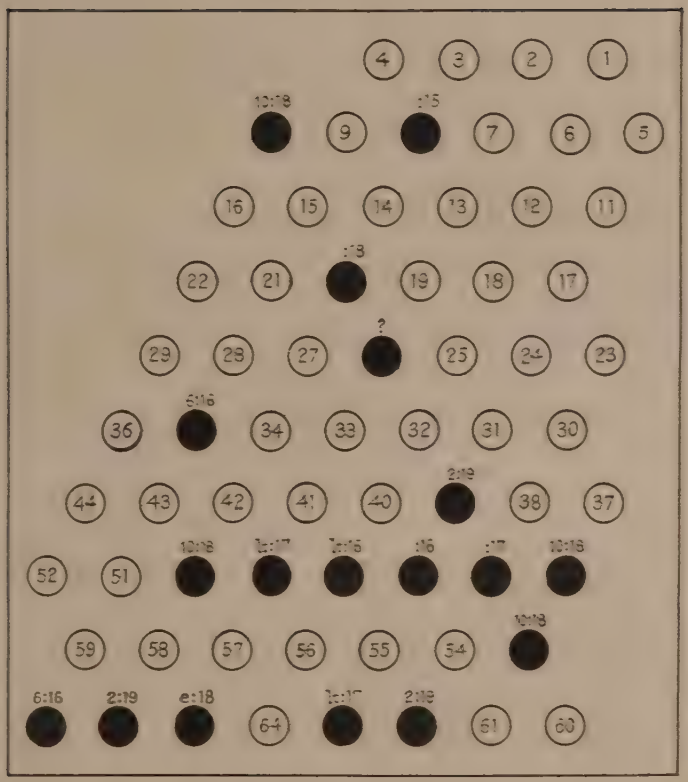


Fig 2. INFESTATION OF THE STALK OF A HALF-GROWN LEAF.

PLATE IX.



LT.—LATE E—EARLY

Plan of the Westerhall Plot, Grenada, February, 1919.

A NEWLY DISCOVERED NEMATODE

(*APHELENCHUS COCOPHILUS*, N. SP.),

CONNECTED WITH A SERIOUS DISEASE

OF THE

Coco-nut palm.*

BY

N. A. COBB,

United States Department of Agriculture.

INTRODUCTION.

The following notes record observations made upon specimens of diseased coco-nut palm, forwarded by Mr. William Nowell, Mycologist to the Imperial Department of Agriculture for the West Indies. Nematised roots of the palm preserved in alcohol, and portions of nematised trunk of the palm preserved in formalin, were almost the sole sources of information with regard to the new parasite. No opportunity has offered for a careful examination of soil adjacent to diseased roots.

This nema belongs to the genus Aphelenchus, Bastian, 1864, and proves to be a new species, for which the name *cocophilus* is proposed. The genus Aphelenchus comprises thirty to forty species, of which a considerable number are serious agricultural pests. Nearly all the species are injurious to plants, but only a fraction of them are known to infest cultivated plants. However, the number of these latter is continually augmenting. Probably a number of the species concerning which at present only anatomical knowledge exists, are also injurious to plants Hence the genus is one of constantly increasing interest to agriculturists. Aphelenchus is closely related to the genera Tylenchus and Heterodera, which include some of the worst pests known to agriculture.

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*When dealing with the material sent for examination Dr. Cobb was under the impression that the disease was mainly a root disease. Some of the remarks and recommendations are made on this assumption. Subsequent work in Trinidad by Mr. Nowell has shown that the disease is mainly one of the stem—a fact which in some measure modifies the recommendations to be made concerning treatment and the prevention of infection.—ED. *W.I.B.*

Description of the Nema.

Aphelenchus cocophilus, n. sp. 1.6 8.6 13. 28-68-17 92. .9 1.1 1.1 1.4 .9 k w

Cuticle and Head: The thin layers of the transparent, colourless naked cuticle are traversed by numerous plain, transverse striæ, all alike except that those near the extremities of the body are somewhat wider (0·6 microns) than those elsewhere. These annules are altered little if any on the lateral fields, where there are only very faint indications of longitudinal wings. There are slightly oblique longitudinal striations due to the attachment of the somatic muscles. The cylindroid neck ends in a subtruncate head, which, at least in alcoholic specimens, is sometimes set off by an almost imperceptible contraction. As the more refractive internal tissues do not approach so near the cuticle in the lip region as elsewhere, there is also contrast in this respect. The lips are completely amalgamated, and the lip region, which is not striated, is flattened in front.

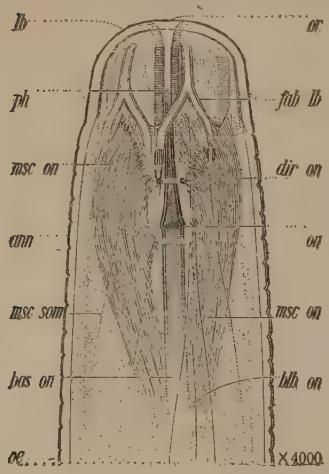

Fig. 1. Head of *Aphelenchus cocophilus*. *lb*, lip region; *pr*, mouth opening; *ph*, pharynx; *fab lb*, frame work of lips; *msc on*, muscles for thrusting forth the spear; *dir on*, guide-ring of the spear; *on*, spear; *ann*, one of the annules; *msc som*, one of the muscles of body wall; *bas on* base of spear; *blb on*, faint bulbous extremity of spear; *œ*, œsophagus.

Digestive Tract: No labial papillae have been seen. In the middle of the lip region occurs the minute, pore-like mouth. The simple, rather regular pharynx is narrow and obscure. The spear, which is about one and three-fourths times as long as the base of the head is wide, is difficult of observation; as a rule, only in the labial region can one distinguish a refractive element indicating the presence of the spear; while there is a definite posterior 'focus' for the muscles which protrude the very slender spear, there seems to be no very definite basal bulb, or similar structure to which they are attached. There are no amphids or eye-spots. The œsophagus is typically aphelenchoid in form, and presents a distinct, well-developed, elongated, median bulb, one-half as wide as the corresponding portion of the neck. There is also an obscure, finely granular, elongated-clavate, cardiac swelling, one-half as wide as the base of the neck. The median bulb is twice as long as wide, and contains a faint, sub-spheroidal, simple valve somewhat behind its centre. The cardiac swelling consists mainly of the salivary glands, the number of which was not clearly made out, but of which there are probably three. There is no disitinct cardia. Gradually the intestine becomes three-fourths as wide as the body, being built up of cells of such a size that probably only about two are required to build a circumference. The walls of the intestine are rather thin, and its lumen faint. From the very inconspicuous anus, the inconspicuous rectum, which appears to be two to three times as long as the anal body diameter, extends inward and forward. The colourless spherical granules scattered in the intestinal cells are of variable size, the largest being one-eighth as wide as the body; they are not so arranged as to give rise to a tessellated effect. The conoid tail of the female tapers gradually from far in front of the anus, to a rather blunt, narrow, rounded, unarmed, symmetrical terminus, which has a diameter one-fourth to one-half as great as the anal body diameter. There is no spinneret, and there are no caudal glands or caudal setae. The excretory pore is in the imme-

diate rear of the oblique nerve-ring, which is of medium size, and is accompanied by obscure nerve-cells. The distance from the median bulb to the nerve-ring is about equal to the radius of the corresponding portion of the neck.

Female Sexual Organs: The two rather slender branches of the female reproductive apparatus are out-stretched in opposite directions from the well-developed but rather inconspicuous vulva; the anterior branch serves as an ovary and uterus, while the posterior branch serves as a spermatheca, in which, at maturity, are usually to be seen sperm-cells up to the number of about sixteen. These sperm-cells have conspicuous, finely granular, spherical nuclei one-half to one-third as wide as the body of the female, and by the uninitiated might be taken for eggs. From the vulva the medium-sized vagina passes inward at right angles to the ventral surface about half way across the body. Its walls are not strongly cuticularized. The straight, elongated uterus, which is separated from the ovary by a distinct constriction, is two to three times as long as the corresponding body diameter, and is of such a size as to contain only one or two eggs at a time. These latter are elongated in form, and have thin smooth shells. They are deposited before segmentation begins. The ovary is narrow and tapering, so that its blind end, which lies four to five times as far behind the median œsophageal bulb as this latter does behind the anterior extremity, is one-third as wide as the corresponding portion of the body. The numerous small ova are packed single file in the ovary.

Male: The posterior part of the male is unlike that of his mate in that the tail tapers differently, the anterior three-fifths of it having nearly the form of a cylinder—i.e. tapering but little to near its middle, where there is usually a sudden decrease of about 50 per cent. in diameter. Thence onward the tail is arcuate, and tapers to the semi-acute terminus. The anus is slightly raised. The tail of the male, at least in alcoholic specimens, is always coiled into a spiral of one to one and one-half winds, the width of the spiral being five to six times as great as that of the body. There is a single testis. The two flat, equal, arcuate spicula lie parallel and very close together, and are not much longer than the anal body diameter. At their widest part, that is at the proximal extremities, they are about one-half as wide as the corresponding portion of the body. As the dorsal elements of the spicula are longer than the ventral elements, the cephala sometimes seem to face almost directly toward the ventral surface of the body. There is a single, rather obscure, somewhat arcuate, rather frail, simple, non-apophysate accessory piece about one-fourth as long as the spicula and arranged parallel to their distal extremities There are no ventral supplementary organs. Two pairs of subventral papillae have been seen, one close in front of the other, just in front of the place where the tail suddenly diminishes in diameter. There appears to be a third subventral pair opposite the middle of the spicula.

FIG. 2. Tail end of the male of *Aphelenchus cocophilus*; *aco*, maleaccessory; *sp*, one of the spicula; *ppl*, male papillae; *trm*, end of the tail: *cop msc*, copulatory muscles.

Habitat. In roots of the coco-nut palm, Grenada, West Indies. Described from specimens preserved by plunging the roots into 70 per cent. alcohol. The nemas were afterward removed from the root tissues and mounted in glycerine jelly for

examination. Males and females in about equal numbers were found to be abundant in the roots. The tissues just beneath the rind of the roots were softened and discoloured, owing to the infestation. Young specimens were also abundant. The following formula gives the dimensions of the smallest larvae found in the roots.

2.8	18.	24.	Y	91		
1.7	2.	2.2	2.5	1.8		.37 mm

The two species of Aphelenchus most closely related structurally to *Aphelenchus cocophilus* are *Aphelenchus elegans*, Micoletsky, and *Aphelenchus helophilus*, de Man. All three species are of about the same general form and size. The following table will serve to indicate various structural differences :—

	COCOPHILUS.	ELEGANS.	HELOPHILUS.
Habitat	...Coco-nut roots	...Water, Lunz, Austria	Soil, Holland, rare.
Tail, female	...Tapers ; narrow, blunt ...	Plump, subacute ...	...Rather plump, acute
Eggs ...	...Long ...	...Long ...	...Ellipsoidal (?)
Excret. pore	...Near the bulb	...Not so near the bulb	Near the bulb
Œsoph, bulb	.. Elongate ...	.. Elongate-ellipsoidal..	Pyriform
Neck ...	...Cylindroid ..	...Tapers some in front	Tapers throughout
Head ...	...Subtruncate	...Rounded ...	...Somewhat rounded
Spear-bulb	...No distinct basal bulb ...	Distinct bulb ...	...Distinct bulb
Spear ...	...Faint, very slender	...Fairly developed	...Fairly developed
Lip-region	...Distinct ; no constriction	...Faint ; no constriction	...Set off by constriction.

Remedial Measures.

Examination of the literature relating to the diseases of the coco-nut palm shows that the West Indian investigators have already suggested a number of appropriate remedial measures. In this connexion, therefore, reference is made to the previous publications of the Imperial Department. The following are additional suggestions based on the present examinations.

Drainage. It should be borne in mind that water is one of the chief agents in the distribution of root diseases caused by nemas, and that the diseases are therefore distributed to a greater extent downhill than uphill. This applies not only to open ditches of flowing water but to distribution *in* the soil, if the soil is an open one ; for there are currents in the soil itself, that is to say, drainage currents that are quite capable of transporting the nemas, and of course always downhill. Possibly it is also worthy of minor note, that diseases caused by nemas, in case the nemas are capable of withstanding desiccation, and are in time brought to the surface of the ground encased in dry, light particles of vegetable detritus, are capable of being transported by the wind, and hence tend, like some insect pests, to spread faster to leeward than to windward. For similar reasons the diseases are more likely to follow the routes of traffic.

Flooding. Many soil-inhabiting and plant-infesting nemas can be drowned; when submerged in water they usually succumb in the course of a few days at most. This suggests the possibility of drowning nemas found attacking the roots of coco-nut palms, and experiments along this line might be advisable. If it turns out that the nemas can be drowned before the palm roots

are seriously injured, this result might lead to the formulation of a method that might prove to be of some economic value. Only experiment can determine this. In this connexion it might also be advisable to test the effect of salt-water. The roots of the coco-nut palm will withstand a considerable degree of salinity, and it may be worth while to determine whether or not salt water would be more injurious to the nemas than fresh water.

Burning. The destruction of all diseased material by fire, or in some other inexpensive way, is strongly advisable. The destruction of orchards should be preceded by an inspection of the roots of the palms it is proposed to sacrifice, to see whether they are actually infested. In case of such drastic action, the inspection might prevent a considerable amount of unnecessary destruction. The inspection should preferably be a microscopic one.

Quarantine. Where legal means exist, plant quarantines can be established that, to a certain extent, will prevent the spread of such diseases as this from one locality to another. In order that quarantine regulations shall work as little hardship as possible, careful attention should be given to the extent to which commerce is thereby hindered. In the case of coco-nuts, there could be little objection, at least from the local point of view, to exporting suspected material to such ports as Liverpool, New York, etc., where there is very slight chance that the disease could cause further injury.

Distribution and Abundance in the Roots. The distribution of the nemas in the roots is correctly described by Mr. Nowell. I find on examining somewhat carefully, that the nemas are most abundant about half way between the outer surface of the root and the central strand. The numerical degree of infestation may be appreciated by considering the fact that, if the roots were uniformly infested at the rate of the part examined, the number of nemas in a root about ¼-inch in diameter would be in the neighbourhood of twenty thousand per linear foot. This is a minimum number, for undoubtedly through the necessary manipulation, a number of nemas were destroyed or lost.

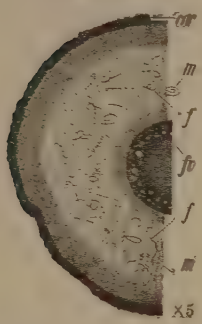

FIG. 3. One-half of a cross-section of a root of coco nut palm infested with the nema, *Aphelenchus cocophilus*. *cor*, bark or cortex of root: *m* and *f*, male and female nemas infesting the root: *fv*, central fibro-vascular bundle of the root.

Furthermore, it is by no means certain that all the nemas present in the material examined were seen and counted. It is therefore certain that the real number per linear foot would be greater than the calculation indicated, possibly much greater. It was not considered necessary to make more than a roughly approximate estimate.

DESIRABLE EXPERIMENTS.

Resistance to Dryness. An early effort should be made to test the degree to which *Aphelenchus cocophilus* can withstand dryness. It is already known that some species belonging to the

genus Aphelenchus can withstand desiccation for a considerable length of time. At the onset of dryness they enter a comatose state, from which, when again moistened, they revive, and then seem practically as active as ever. This suggests the advisability of caution in collecting coco-nuts for seed. It will be readily conceded that on coco-nut areas infested by this nema, there are plenty of chances of contamination. Should this nema, like many of its confreres, prove resistant to dryness, then old decomposed, nema-infested coco-nut roots and portions of trunk, brought to the surface of the ground, weathered and reduced to fragments, and hence composing a not inconsiderable portion of the surface detritus, may serve as a means of spreading the disease. Such fragments, even when very minute, might easily contain desiccated nemas. (See Fig. 4.) Unless a certain degree of cleanliness and caution is observed, nuts gathered on infested areas might by adhesion easily carry infested dirt, and so afford the nema a chance to spread from one place to another. The history of many diseases caused by nemas shows that they are inadvertently transported in some such way by human agencies to a greater extent than in almost any other. This is a matter in which cultivators and others are shockingly careless.

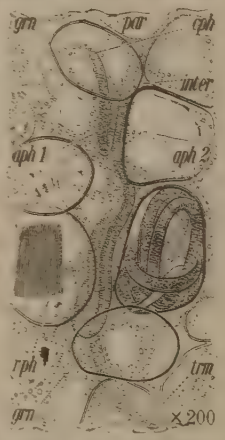

FIG. 4. Sketch showing manner in which *Aphelenchus cocophilus* occurs in the parenchymatous tissue of the trunk of the coco-nut palm. *aph* 1 and 2, two individual nemas as fixed in formalin; *cph*, head end of a nema lying in the intercellular space; *inter*, *trm*, tail end of same; *par*, parenchymatous cell of palm; *rph*, raphides in another cell; *grn*, one of the granules in the more or less disintegrated contents of one of the cells. All the palm-cells shown are dead. *The material here shown could be contained in a particle of trash only one one-hundredth of one inch long.*

In general, as little material should be transported from a diseased area to one not diseased as is consistent with the practical conduct of business. A little thought will disclose that this means a great deal more than will at first occur to the average person.

Artificial Infestation. Another important line of experiment should be undertaken at once—that of attempting artificially to infest healthy roots. Diseased roots and soil from about diseased roots should be laid alongside healthy coco-nut roots, in a definite manner at permanently marked locations, and then covered in. These hitherto healthy roots should then from time to time be disinterred and examined for signs of nema infestation. No time should be lost in making this experiment. Positive results from it will not only serve further to establish the nema as the cause of the disease, but will also give information as to the exact method of attack, and the rate of onset.

Length of Life. Infested roots should be stored both in the ground and above ground, and examined from time to time in order to determine how long the nemas will live in such material. The results of this experiment and the preceding will have a very important bearing on the application of a number of remedial measures

Other possible Hosts. It is very desirable that the roots of other plants growing in the vicinity of diseased coco-nut palms be examined in order to ascertain whether or not they are infested by this nema. The results of such investigation will have a very important bearing on the remedial measures to be taken. It is one matter if the nema is peculiar to the coco-nut palm, and quite a different matter if it also infests plants other than the coco-nut palm. While it is a rule that a parasitic nema infests but one host-plant or only a few related species, there are very striking exceptions to this rule, and no strict deduction can be made from the facts hitherto discovered. From this it follows that in this respect each parasitic nema must be considered by itself. There are enough cases where a given species of nema infests a wide-

NOTICE.

Through an oversight the measurements of *Tylenchus musicola*, Cobb, described on pp. 180-2 of the *West Indian Bulletin* Vol. XVII, No. 3, were omitted. These measurements are as follows. The total length of the female being ·66 mm. and that of the male ·51 mm. The other measurements are given in percentages of these lengths in the usual manner:—

3.	12.	15.	48 - 81	93·		
2·3	3.	3·1	3·2	2·4		·66 mm
3·8	15·	19	42 - M	95·7		
1·9	2·5	2·7	2·8	2·3		·51 mm

palm. *epi*, head of embryo; *bb*, oesophageal bulb; *nr*, nerve ring; *oe*, oesophagus; *teg*, shell of the egg

that just as certain insect pests have been controlled through the agency of their insect enemies, so injurious nemas may come to be controlled by their nema enemies.

Eggs. The eggs of *Aphelenchus cocophilus* are deposited in the tissues of the host plant where they hatch out and then invade fresh tissues. This method of reproduction is one almost necessarily fatal to the palm, once the infestation has reached the base of the trunk. Combative measures must therefore be largely preventive.

Salivary Glands. The material thus far investigated does not permit of a satisfactory examination of the salivary glands.

As it seems possible that the state of development of these glands is some indication as to the food habits of such nemas as the Alphelenchi, it is advisable that further examinations of these organs be made in *A. cocophilus* and other triplonchs. A notable fact is that, so far as investigations of the triplonchs have proceeded, the salivary glands are more strongly developed in those species which are serious plant pests than in other species. If this proves to be generally true, the state of development of these glands will serve as a guide in judging the possible injuriousness of newly discovered triplonchs, such as this.

THE IMPROVEMENT OF THE YIELD OF SEA ISLAND COTTON IN THE WEST INDIES BY THE ISOLATION OF PURE STRAINS.

PART II.

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INTRODUCTION.

In the first part of the paper (*West Indian Bulletin*, Vol. XVII No. 3) the various morphological characters of the Sea Island cotton plant which could affect the yield of lint per acre were analysed. It was pointed out that by self-fertilization and selection, many distinct strains can be isolated from Sea Island cotton, and that the stable combinations of morphological characters affecting the yield, which emerge as a consequence of strains becoming homozygous through self-fertilization are of varying merit. The object of the cotton breeder is to produce a strain of high grade lint possessing also an optimum association of those morphological characters which affect yield.

The present paper contains a discussion of a further series of St. Vincent results, but is mainly concerned with a detailed analysis of certain data accumulated by Mr. William Robson, during the course of his cotton breeding experiments in Montserrat.

Cotton selection has been carried on in Montserrat for several years, but it was not till 1916 that the method was adopted of using only self-fertilized seed, and of examining certain characters of every individual in a progeny row. Mr. Robson, Curator of the Botanic Station in Montserrat, has recorded the data in his cotton breeding work for the years 1916-18, and the present writer is indebted to him for facilities for analysing the results.

In regard to the data from both Montserrat and St. Vincent, what has been done is to set out briefly the chief conclusions which are to be drawn, to discuss certain correlations of economic importance which have been brought to light, and lastly, to indicate along what lines future work may best proceed.

Materials and Methods.

The Montserrat strains divide themselves into three groups. Two of the groups are descended from single plants H.9-23 and H.9 Th., grown in 1915, and the third group from a single plant, D.1, grown in 1916. In each season the plants have been self-fertilized by the copper-wire method. The characters examined were: (a) mean maximum length of pulled lint, in mm. (on 5 seeds), (b) weight of lint per seed in mg. (on 100 seeds), (c) mean seed weight in mg. (on 100 seeds), and (d) number of bolls to the pound of seed-cotton. The last character was not recorded for the individual plants, but only for the whole progeny row. The result is calculated from the weight to the nearest ½-oz. of four lots of 100 bolls picked at random from the row at weekly intervals.

The St. Vincent strains are all descended from single plants grown in 1915. Self-fertilized seed only has been used in the experiments. Weight of lint per seed and mean seed weight have been recorded in the same way as for the Montserrat strains, but no data for the number of bolls to the pound of seed-cotton are available. Mean maximum lint length was not measured on lint pulled from the seed, but by the halo method. A careful comparison of the results obtained by both methods has been made, and indicates that measurements of pulled lint are about 2 per cent. below those obtained by the halo method. The halo method is undoubtedly capable of giving more accurate results.

The following brief statement will make clear the method of numbering the plants and strains. H.9 is a single plant. Seeds of it are sown in a progeny row which is called family H9. The individual plants of the row are numbered H.9-1, H.9 2, H.9-3, etc. If a progeny row from plant H.9-1 is grown, the row is called H.9-1, the individual plants in it being numbered H.9-1-1, H.9-1-2, etc. Thus the line of descent of any strain or single plant is shown by a simple inspection of its number.

This method of numbering is practically identical with that introduced by D. H. J. Webber (1906).

The Results.

THE MONTSERRAT RESULTS FOR MEAN MAXIMUM LINT LENGTH.

Table I shows the frequency arrays of the Montserrat strains for mean maximum lint length. It is necessary to state, that in Montserrat the plants may show shorter lint in certain seasons owing to drought. The season in 1918 was very dry during the maturing period of the bolls, and the lint is shorter than in previous years. Nothing is advanced here in the way of proof of the above statement, but it has been made fairly

clear that water shortage lowers lint length by Balls's work in Egypt 1915), by a suggestive set of data in a paper by Kelsick (1918), and also by some unpublished data of the writer. Robson has also suggested that drought shortens lint length.

The chief features of Table I are as follows:—

1. In 1916, all three parent strains H.9-23, H.9-Th., and D.1 show relatively little variation in lint length. None of the plants have a lint length of below 49 mm. It is well known that in ordinary commercial fields of Sea Island cotton, plants with lint lengths of 30-33 mm. are not uncommon, and it would seem that the continuous selection for uniform length, carried on by Robson, during the several years previous to 1916, had had the effect of eliminating the tendency to produce short lint. According to expectation, no short-linted plants have appeared in subsequent years.

2. The differences in range of the three 1916 strains indicate that, although the tendency to produce short lint had been eliminated, yet it is certain that the strains were not composed of a single genotype. From an inspection of the 1917 data, the present writer advised the selection of the three plants in strain D.1-16 with the longest lint, on the ground that this strain showed a frequency array of range much above any other strain grown that year. Accordingly, two plants were grown on in 1918, producing strains D.1-16-7, and D.1-16-19. While the means for these families are below that of the parent strain, owing probably to drought, they retain the relative superiority in length possessed by the parent type, being higher than any other strain grown in 1918. These two strains may be regarded as a definite advance in lint length, although it cannot as yet be said that they are pure strains.

3. If the longest lint possible were the main thing to aim at in selection, it is probable that selection in strain H.9-Th. would have resulted in the isolation of types with longer lint than any that have been produced. The selection of the six plants in that strain with lint length of 55 mm. and above, would conceivably have originated strains of similar range to D.1-16 and its two daughter families, and possibly still higher. The composite nature of H.9-Th. is shown by the fact that selection of the plant with the longest lint in 1917 (strain H.9-Th.-16-4) resulted in 1918 in a family with a longer lint than that of the other strains descended from H.9-Th.

4. Since slight differences in lint length are heredetary, it is obvious that two plants may have precisely the same lint length, but give rise to progeny of widely different means. Thus a lint length of 54 mm. may be the lowest point of a long strain or the highest point of a short strain. In other words, the somatic expression of length may be different from the genotypic. The measure of the worth of a plant in regard to lint length can only be measured by expressing it in terms of the progeny-behaviour of its progeny.

5. Both samples of the 1916 [illegible] were sent to the British Cotton Growing Association for report by [illegible] tests. The strains which have been alluded to above as being behaviour longer than the test are D.1-16-7, D.1-16-19, and H.9-Th.-16-4

and of these, D.1-16-7 was unfortunately not sent. The other two are commented on as follows :—

D 1-16-12. 'Fully one to extra fine, but wasty and irregular in length.'

H.9-Th.-10 4. 'Extra fine, long and silky staple.'

Thus the extreme length of the first of these two strains receives no comment. The length of H 9-Th.-10-4 is mentioned, but it should be stated that strain H.9 28-2-16, which is 3 mm. shorter than H 9 Th.-10-4, and is therefore one of the shortest types of 1918, is commented on in precisely the same language. It has been clearly demonstrated that these differences in lint length, though slight, are hereditary, and can be maintained from season to season. The inference is, that the methods of judging lint length used by workers in the West Indies are more accurate than those used by the broker.

6. It is no part of the present writer's intention to enter into a discussion as to whether it is desirable to grow the longest lint possible in Montserrat. A 53 mm. cotton, if regular and uniform, would probably be worth more to the spinner than one of 48 mm. The spinner can have which length he prefers, subject to seasonal fluctuation; but up to the present we are entirely in the dark as to which suits him better.

7. It should be noted, that in the original 1916 families very few plants are at present capable of producing long-linted progeny. If only six plants are available with the probable capacity to develop strains of long lint, and if only two of the plants actually have that capacity, it is evident that the smallest possible chance exists of obtaining by continued selection a strain combining every, or even many, advantageous morphological characters. Such a strain could only be developed by a process of synthesis.

8. In general, the Montserrat results show that the lint length of the strains under examination was excellent, even in 1916, and it is probable that subsequent selection has effected no improvement of commercial importance.

THE ST. VINCENT RESULTS FOR MEAN MAXIMUM LINT LENGTH.

The frequency arrays for mean maximum lint length of the St. Vincent strains will be found in Table II. The data are not very full, but it may be noticed that the B.S. strains are consistently shorter than all the other strains. The tendency to produce very short lint has also been eliminated from the St. Vincent strains.

THE MONTSERRAT RESULTS FOR WEIGHT OF LINT PER SEED.

The writer has shown in the first part of this paper that lint weight (weight of lint per seed) is one of the most important of the "combined" characters affecting yield of lint per acre. It is therefore desirable for a strain to have the highest possible lint weight consistent with high grade lint. In Table III will be seen the frequency arrays for lint weight of the strains of Montserrat.

The most important features of Table III are as follows:—

1. The great variability of the 1916 families is much lessened in the two following seasons. The results admit of a clear interpretation. Self-fertilization has had the effect of reducing the variability of the types, and selection has isolated strains of much higher lint weight than has hitherto been recorded for Sea Island cotton.

The work in Montserrat has proceeded along the same lines as in St. Vincent, but while the present writer, working in the latter island, isolated by selection a strain with a mean lint weight of 50 mg., (V.32-3-1) from a commercial strain with mean value 40 mg., Robson was able to get the mean value of 50 mg. in 1916, and has since obtained in Montserrat the two extraordinary strains H.9-23-2-13 (mean 60 mg.), and H.9-23-2-15 (mean 56 mg.). On the other hand from the strain H 9-Th. has been isolated H.9-Th.-10-4, with the low mean of 38 mg., practically the same as its parent family (41 mg.).

2. The descendants of D.1 have in general much lower value than those from H.9 or H 9-Th. Two very low strains, D.1-16-7 and D.1-16 19 have been isolated. It is, however, clear that had selection for high lint weight been carried on in the descendants of D.1, types with much higher lint weight could have been produced, for it is to be noted that the range of D1-4-10 runs up to 56 mg.

3. From an inspection of the 1917 Montserrat data it was concluded by the present writer, that family H.9 23-2 was genotypically of higher lint weight than any strain bred that year, and it was advised that all plants in that strain of every high lint weight be grown on in 1918. Five strains were accordingly examined in the latter season, and the results show that the strains may be classified into two groups. One group possesses roughly the same mean value as the parent strain. A summary of the five strains under discussion is shown below for convenience :—

Strain.	Lint weight.	Seed weight.	Parent lint weight.
H.9-23-2-1	49	120	68
H.9-23-2-13	60	133	60
H.9-23-2-15	56	133	61
H.9-23-2-16	55	130	59
H.9-23-2-17	52	120	62

The three high strains have high seed weight (130-133). The two low strains have low seed weight (120). It will be shown later, that there is a strong correlation between the lint weight and the seed weight of a group of strains, and it is evident that if strains of high lint weight are required, the seed weight must also be high. A type may be genetically of high

lint weight, but if the seed weight is low, then the high lint weight cannot find expression. This is an excellent example of what is called by Balls 'autogenous fluctuation.' The present writer has observed, that a cross between two types, both of low lint weight, may give rise in F_2 to plants with lint weight higher than either parent. This may be due partially to recombination of Mendelian factors, and partially to the fact that the genetically high lint weight of one parent, which was before unable to find expression owing to the low seed weight, now shows itself in the plants of high seed weight brought in by the other parent.

As seen above, selection of a very high lint weight may give progeny with a comparatively low mean, owing to the complication caused by seed weight. To obtain strains of high lint weight, it is necessary to grow progeny rows from a large number of plants of the highest lint weight obtainable. It is clear that selection must not be confined to one plant.

THE ST. VINCENT RESULTS FOR WEIGHT OF LINT PER SEED.

The frequency arrays for weight of lint per seed of the St. Vincent strains are presented in Table IV. The following are the chief points brought out by this table :—

1. The B.S. strains appear to breed true to a mean of 34-35 mg. Selection of the highest value in B.S.1-53 produced family B.S. 1-53-7, the mean of which was exactly the same as the parental and grand-parental families.

2. In 1917, family V.3 32-3 had a mean of 50mg., and a range considerably above any other family grown that year, if we except the very long-ranged family V.5-61-28, which produced one plant with lint weight 59 mg. An attempt was made to raise the mean lint weight of V.3-32-3 by selecting a number of plants in it with the highest values. Six families were grown in 1918, but an examination for lint weight of bulk samples of each family showed that no progress has been made. The mean lint weight of the six families ranged from 48 to 50 mg. From the Montserrat results it has been seen that strains of very high lint weight must also have high seed weight. Since the mean seed weight of all families descended from V.3-32-3 is about 120 mg., it is clear that further selection in this strain for a lint weight above 50 mg. is useless. There is no possibility of producing from the St. Vincent material, a strain equal to H.9-23-2-13 (mean 50 mg.).

THE MONTSERRAT RESULTS FOR MEAN SEED WEIGHT.

In Table V will be found the frequency arrays for seed weight of the Montserrat strains. The following are the chief points to be noted :—

1. In 1916, strains H.9-23 and H.9-Th. have an extremely long range, while D.1 has a shorter range.

2. Selection and self-fertilization have led to a reduction in variability, so that in 1918 certain strains appear to be breeding fairly true. Note in particular, families, D.1-16-7 and D.1-16-19, both of which are low, and of approximately the same mean as the parent strain.

3. No strain has been isolated with so many plants of high seed weight as family H.9-Th, and it would seem that the very high seed weights have been eliminated from this type by selecting the lower values. Since a high seed weight is desirable, it is clear that the present case provides an illustration of the chief danger of pure strain work with cotton—elimination of desirable genotypes through ignorance of their good qualities.

The results for the St. Vincent strains are presented in Table VI. No particular comment upon them is required, but emphasis may be laid upon the fact that in general, the seed weight is too low.

THE MONTSERRAT RESULTS FOR NUMBER OF BOLLS TO THE POUND OF SEED COTTON.

In Table VII will be found the Montserrat data for 1917 and 1918 for number of bolls to 1 lb. of seed-cotton, weight of seed cotton andof lint per boll in grams, and pounds of lint per acre. The strains were grown in single rows, each row being one-hundredth acre in area in 1917, and one-sixtieth acre in 1918. The spacing was 5 feet by 2½ feet in both years. Since only one row was grown of each strain it is evident that even large differences in yield may be quite devoid of significance, owing to the large probable error involved. A summary of the chief conclusions to be drawn from the data in Table VII is as follows :—

1. The number of bolls to the pound of seed-cotton is another way of expressing the weight of seed-cotton per boll. The value of the latter depends on : (a) the weight of seed per boll and (b) weight of lint per boll. It has been pointed out in the first part of this paper that weight of lint per boll is the resultant of two chief factors : (a) number of seeds per boll, (b) weight of lint per seed. The number of seeds per boll is affected by the number of loculi in the boll and by the number of seeds in each loculus. Both these characters show well-marked hereditary differences in different strains. The weight of lint per seed is correlated with seed weight. If a strain has a high weight of lint per boll, it would seem that it should also have a high weight of lint per seed and a high seed weight. Thus a high positive correlation between lint weight and lint per boll should result. This point will be discussed later.

2. In 1917 the weight of seed cotton per boll ranged from 2·41 gm. in D.1-16 to 3·82 gm. in H.9-23-2, and H.9-Th-36. There is a 60 per cent. difference in favour of the two latter strains. In 1918, five strains were grown from H.9-23-2. The weight of seed-cotton per boll was increased to 4·02 gm. in H.9-23-2-15, and to 3·91 gm. in H.9-23-2-13. Two strains were grown from D.1-16. Family D.1-16-7 had 2·84 gm. and D.1-16-19 had 2·37 gm. of seed-cotton per boll. Thus the weight of seed cotton per boll is hereditary, and can be increased by selection from a field population. The highest strain in 1918 is 70 per cent. more than the lowest.

3. In 1917, the weight of lint per boll ranged from 0·59 gm. in D.16 to 1·12 gm. in H.9-23-2. The difference in favour of the latter is 90 per cent. In 1918, five strains were grown from

H.9-23-2, and in one of these, H.9-23-2-13, the weight of lint per boll was increased to 1·22 gm., representing an increase of 100 per cent. over the lowest for 1918, family D.1-16-19, which had a value of 0·61 gm.

4. From the point of view of the practical cotton breeder, weight of lint per boll is a character of the utmost importance. Weight of lint per boll should be recorded for each plant, on not less than fifteen bolls It need not, however, be recorded for types of low lint weight, for it will be shown later that high lint per boll is only found in association with high weight of lint per seed. It is interesting to note the following statement of Balls and Holton (1915): 'Since an increase in boll weight would be directly projected as an increased yield, it may be advisable to comment on its nature. No variety of Egyptian cotton at Giza has yet produced more than 2 gm. of seed-cotton per boll under any treatment, or in any season. On the other hand, boll weight was determined, . . . in the Middle Delta, where the weather is cooler, and it was found that the boll weight there rose higher in soil with a deep water table: from 2 grm. with shallow soil it rose nearly to 3 grm. in deep soil.' It is evident that the boll weight of Sea Island cotton is, on the whole, greater than that of Egyptian.

CORRELATIONS.

LINT WEIGHT CORRELATED WITH OTHER CHARACTERS.

(a) *Lint weight of Parent and mean lint weight of Progeny* The coefficient for lint weight of parent correlated with mean lint weight of progeny in forty six Montserrat strains is 0·82±0·03, and in twenty-four St. Vincent strains the coefficient has the same value. This indicates that plants of high lint weight tend to produce progeny of high lint weight. The correlation also implies that genetic differences in lint weight are present in the strains under examination, for correlation between parent and progeny in pure strains should be sensibly zero. If strains of high lint weight are desired, selection should begin with as large a number as possible, of plants of high lint weight. The measure of the worth of any particular plant lies in the average behaviour of its progeny. Selection should not be confined to a few plants.

(b) *Lint weight and Lint length.* The coefficient for mean lint length correlated with mean lint weight in a group of twenty-three Montserrat strains is −0·83±0·04. In a group of thirty-six St. Vincent plants selected at random from a field population, the correlation is −0·55±0·08. Both these values are substantial and statistically significant. On the other hand, the coefficient between these two characters in the Montserrat strain H.9-Th.of 1916, is sensibly zero, being −0·11±·11.

It is important to remember that the amount of weight carried by a correlation coefficient depends on whether the data from which it is calculated is a fairly average sample of strains or single plants in general. Thus in calculating correlation between lint length and lint weight, the range of variation of both these characters in the data used should cover the whole range of variation possible in Sea Island cotton. Preponderance of any given com-

bination tends unduly to influence the correlation coefficient in one direction.

Is it permissible to conclude from the two negative correlation coefficients that have been found, that long and high lint weight are antagonistic? The view taken by the present writer is that these negative correlations, although statistically significant, should be looked upon with some degree of caution. Both are based upon a small number of observations, and the presence of only a small number of chance combinations of high lint weight and short lint, or low lint weight and long lint would tend to produce a minus correlation. What is perfectly clear is that no combination of very long lint (above 55 mm.) and high lint weight (above 55 mg) has yet been shown to exist in Sea Island cotton. The longest linted cottons under commercial cultivation are the Superfine Sea Island cottons of St. Vincent. In a typical Superfine plant the lint weight is low (29-35 mg.), and the lint length is from 55-60 mm. It will be pointed out later that there is a high positive correlation between weight of lint per seed and weight of lint per boll, and a positive correlation of simlar magnitude also exists between weight of lint per seed and weight of lint per acre. It has been a matter of common knowledge among planters that Superfine cottons are lower yielders than the ordinary type of Sea Island, and this observation now finds a reasonable explanation in the low weight of lint per seed and consequent low weight of lint per boll of these types. If the lint weight of Superfine were raised by selection, and this could undoubtedly be done, the yield per acre would become greater. If, however, long lint and high lint weight are antagonistic, the danger creeps in of losing the longest linted types, in which case the cottons could no longer be classed as Superfine.

The whole question of the relation of lint length to lint weight should now receive the fullest investigation by a study of a cross between a strain of high lint weight and short lint, and one of low lint weight and long lint.

It may be noted that Balls (1915) does not regard as tenable the dictum that 'the longer the staple of cotton the lower must be the yield.'

(c) *Lint weight and seed weight.* In forty-seven Montserrat strains the co-efficient of correlation between these two characters is high and positive. $r = 0{\cdot}73 \pm 0{\cdot}05$. Lint weight and seed weight are necessarily correlated because the amount of lint on the seed is limited by the size of the seed. For a seed of a given size there is a maximum possible weight of lint which is less for a small and light seed than for a large and heavy one. Thus the following combinations are possible : heavy seed and heavy lint, heavy seed and light lint, and light seed and light lint. The combination of light seed and heavy lint is a physiological impossibility. It should be noted that the combination of heavy seed and light lint is not represented in the Montserrat strains.

The observation that lint weight and seed weight are correlated is not new. Balls (1909) states that there is a strong correlation between the weight of a seed and the weight of lint which that seed bears. He further states that the cause of variation in ginning out-torn is due to the fact that the corelation between these two characters is incomplete.

(d) *Lint weight and Lint per boll.* The co-efficient for lint weight correlated with lint per boll is high and positive, the value of r being 0·90±0·02 in forty-nine Montserrat strains grown in 1917-18. The existence of this correlation is to be expected since lint weight is one of the chief components of lint per boll (lint per boll = lint per seed × seeds per boll).

(e) *Lint weight and Lint per acre.* For the Montserrat strains of 1917, the correlation coefficient is 0·56±0·08, while in 1918 it is higher, being 0·75±0·06. Thus lint weight is again seen to be of the greatest importance in breeding Sea Island cottons for heavy yield.

LINT LENGTH CORRELATED WITH OTHER CHARACTERS.

Lint length of Parent and mean lint length of Progeny. The correlated coefficient for these two characters for twenty-three Montserrat strains is 0·72±0·07—high and positive. Long-linted strains can only be derived from long linted parents, and as was stated in the discussion of the correlation between lint weight of parent and progeny, the mean of the strain must be used as a guide in selection, and not the character of the individual plant. It may be laid down with a fair degree of certainty, that a strain of long lint cannot be derived from a short-linted parent.

SEED WEIGHT CORRELATED WITH OTHER CHARACTERS.

Seed weight of Parent and mean seed weight of Progeny. The correlation coefficient for these two characters in forty-seven Montserrat strains is high and positive, being 0·71±0·05. Strains of high seed weight originate from parents of high seed weight. The starting point in selection must be a large number of plants of high seed weight. The behaviour of the progeny of such plants will indicate which plants were genetically high, and which were merely high through fluctuation.

LINT PER BOLL CORRELATED WITH OTHER CHARACTERS

Lint per boll and Lint per acre. Since a high positive correlation was found between lint per seed and lint per boll, and also between lint per seed and lint per acre, it might be expected that the correlation between lint per boll and lint per acre would also be high and positive. This expectation is realized for the value of r for twenty-seven Montserrat strains in 1917, is 0·54±0·09. In 1918 it is larger, being ·84±0·04.

LINT PER ACRE CORRELATED WITH OTHER CHARACTERS.

Lint per acre of strain and Lint per acre of parental strain. If all the strains were grown under ideal environmental conditions, and all produced the same number of bolls per plant, it would be easy to pick out the highest yielding strains by estimating weight of lint per boll. The existence of a significant positive correlation between yield of parent strain and yield of daughter strain, r = 0·46±0·12, indicates that hereditary differences in yield do occur in the Montserrat strains, and that

fluctuation in yield due to soil conditions, etc, have not been great enough to mask hereditary differences in yielding power. It would seem that estimations of yield of strains, even when based on single rows, serve a useful purpose in eliminating very low yielders.

General Considerations.

The results of three years' breeding work with Sea Island cotton have now been discussed, and it is advisable to set forth some general considerations arising from the work as a whole.

In the first place, both in St. Vincent and in Montserrat, it has been shown that Sea Island, as commercially grown, is composed of a mixture of distinct strains, which can be separated by self-fertilization and selection. Both from the point of view of yield and of the commercial value of the lint, these strains are of varying value.

Length of staple would seem to be one of the main factors in determining commercial value. Regularity of staple, which can be judged by estimation of available fibre, is probably largely influenced by amount and distribution of rainfall, and an island like St. Vincent, which usually has an even distribution of rainfall, will perhaps always produce a more valuable product than Montserrat or St. Kitts.

Montserrat can produce a good 48·51 mm. staple, which appears to be entirely satisfactory to the spinner. The negative correlation which appears to exist between lint length and lint weight, and thus also with yield of lint per acre, need not be strongly pressed. Much more evidence is still needed on the question, and it must be borne in mind that statistical constants based on a small number of strains are apt to be misleading. This much may confidently be said. Montserrat has a type of cotton with an amount of lint per boll nearly double that of ordinary c mmercial strains, with a correspondingly heavier yield. If the spinners are led to complain of the spinning properties of this type, it may then be the business of the Agricultural Department to provide another type which can easily be done. Meanwhile, it would seem best to propagate the heaviest yielding type as quickly as possible.

It must be obvious to all who are concerned with cotton breeding work, that the improvement of Sea Island cotton is a peculiarly difficult matter. Before a new strain can be recommended for cultivation on a commercial scale, it must be tested at all possible points. It must possess satisfactory physiological as well as morphological characters. An example will serve to illustrate this point. After four years' work a strain was isolated in St. Vincent which appeared to be desirable in every possible respect. Just when it was about to be put into commercial cultivation, it proved to be undesirable. It was susceptible to bud-shedding, and the seed would not give a good stand of plants owing to some constitutional defect. The inference is obvious. As long as the attempted improvement of Sea Island cotton is carried on by the mass selection method, there is little danger of losing desirable, or of perpetuating undesirable, characters to any great extent. With the adoption of the pedigree selection method

arises the possibility that a desirable character may be dropped out at any point through lack of knowledge as to its importance, and that an undesirable character may be obtained in a homozygous condition.

The work of Sea Island cotton breeding has now become a complex business, and if the work is controlled by those who are not thoroughly familiar with its difficulties, the results produced are quite likely to be disastrous.

In three years in Montserrat and St. Vincent, certain definite results have been achieved. When the whole series of results is scrutinized, it is clear that a good deal of work could have been saved at the outset, if definite ideas had been held as to what was really required. A type of lint weight 60 mg. has been obtained. What are the steps which led to its isolation? In the first place it originated in a family which had a mean and an upward range in excess of the other strains.

Its own range is from 50 68 mg., and it is clear that selection must begin with a number of plants of lint weight not less than 50 mg. In 1915 the present writer made an examination of the lint weight of several hundred plants from a commercial strain. Only two plants out of those examined had a lint weight of 50 or over, and subsequent work has shown that in the descendants of these plants it is impossible to get a mean lint weight of more than 50.

The present strain of ordinary Sea Island cotton grown in St. Vincent is descended from a single plant selected in 1913. Many thousands of plants have been examined in field populations of this strain, and no plant has been seen with lint weight above 55 mg. It would appear useless to attempt to obtain from St. Vincent field population, by ordinary methods of selection, a strain of mean lint weight 60 mg. such as has been developed in Montserrat. The particular combination of genetic factors necessary for the production of very high lint weight has evidently been eliminated from the St. Vincent material. Selection in St. Kitts has probably resulted in the same state of affairs, for the mean lint weight of the commercial type grown in that colony is even lower than that grown in St. Vincent.

One method is left whereby the lint weight of St. Vincent and St. Kitts can be improved, namely by hybridization with the Montserrat strain H.9-23-2-13 (lint weight 60 mg.). There is a tendency among cotton workers to regard with suspicion methods of cotton breeding involving artificial hybridization. In the past, attempts have been made to evolve new types of cotton more suited to West Indian conditions, by hybridizing Sea Island cotton with West Indian indigenous cottons. All these attempts were unsuccessful, the reason being that in the second generation of such crosses appeared an enormous number of different types. None of these resembled either parent, and none possessed the particular combinations sought for. These crosses, however, involved inter-specific types, differing markedly in every measurable character. What would happen if hybrids were made between two pure strains of Sea Island, the characters of which were definitely known? The second generation would be composed of Sea Island plants possessing various combinations of parental characters, resembling in appearance an ordinary

field population, and probably not more heterozygous. Since selection at present begins with complex natural hybrids of unknown parentage, it is reasonable to suppose that better results will be obtained if the starting point for selection is a group of second generation plants out of a cross between two pure strains, provided that this cross is made with the deliberate intention of producing certain combinations.

The remarks which have just been made on the advisability of introducing artificial hybridization into cotton selection work must not be taken to imply that the work of isolating desirable new strains from commercial material must cease. The fullest possible advantage must be taken of the great variation existing in that material, and isolation of desirable new strains should be prosecuted with the greatest energy. It is clear that the Montserrat work has suffered to some extent from the fact that three strains only have been worked with. By a fortunate circumstance, families H.9-23 and H.9-Th. contained valuable material, but it is quite possible that these might have been as inferior as D.1 has proved to be.

Having disposed of these preliminary considerations, it is now possible to set out a practical method for the improvement of Sea Island cotton which will give valuable results in a comparatively short time, and by which the dangers alluded to above as arising in a pure strain work are not likely to occur.

A Method of Improving Sea Island Cotton.

1. From a commercial field of Sea Island cotton or from the F_2 of a cross between two S.I. strains, select about 300 plants. Examine the plants for the following characters :—

(a) Mean maximum of lint (on five seeds).
(b) Weight of lint per seed (on 100 seeds).
(c) Seed weight (on 100 seeds).
(d) Weight of lint per boll (on fifteen bolls).

No plant should be selected of lint length less than 50 mm., lint weight less than 47 mg., seed weight less than 130 mg., or lint per boll of less than 0·90 gm.

2. Grow all the selected plants in progeny rows of twenty plants in the following year. At the time when the first bolls are opening, make an examination of the rows, rejecting all rows which are undesirable from the general vegetative point of view. Bearing in mind the fact that number of bolls per plant is of the highest importance from the point of view of yield, a row may be rejected for the following reasons :—

(a) Greater susceptibility to the Angular leaf spot disease than its neighbours, (b) obvious liability to shedding of either bolls or buds, (c) inability to produce a good stand.

Gather a bulk sample of seed-cotton consisting of 200 bolls from each of the remaining rows. Record the characters as follows :—

(a) Lint length on twenty-five seeds.
(b) Weight of lint per boll.
(c) Weight of lint per seed.
(d) Seed weight.

The last three characters can be recorded by weighing the seed- cotton, and then weighing the lint, after hand-ginning. The only test of the inherent worth of a plant is the average behaviour of its progeny, and the results of the bulk sample test will enable the observer to eliminate all the poorer types. Select the best six rows, and examine the characters of each plant, in the same manner as stated in 1. No row should be selected with mean lint length of less than 48 mm., lint weight less than 50 mg., seed weight less than 130 mg., or lint per boll of less than 1.10 gm. After the six rows have been examined, the best three hould be self-fertilized

3. Plant progeny rows in the next year of twenty plants, of all plants in the best three rows. Again at the fruiting stage eliminate any rows which are undesirable vegetatively, and examine bulk samples form the remaining rows as in the previous year. elect the two best rows from each group for examination of individual plants. At this stage the strains should be in a condition of relative purity, and either or both can be selected for propagation on a large scale.

The principles which are followed in the above method of selection may be summed up thus :—

1. Full advantage is taken of the great variation existing in commercial Sea Island cotton, and in the F_2 generation of Sea Island crosses.

2. The bulk sample method of examination gives an approximately correct idea of the average behaviour of all plants in the row, thus enabling the observer to eliminate types which show themselves genotypically inferior.

3. Practical use is made of the correlations which exist between :—

(a) Weight of lint per seed and weight of lint per boll.
(b) Weight of lint per boll and weight of lint per acre.
(c) Weight of lint per seed and weight of seed.

4. The unit of selection is not the individual plant, but the mean of its progeny.

GENERAL SUMMARY.

Experiments have shown that by self-fertilization of commercial Sea Island cotton many distinct strains can be isolated. From the point of view of both grower and spinner, these strains are of varying merit, and thus the isolation of strains superior in yielding capacity to the types commercially grown becomes a matter of importance.

Since the quality of the lint produced by the grower must be satisfactory to the spinner, the question of the effect of selection on lint length isdealt with at some length in this paper. The following are points of importance which it is necessary to emphasize :—

1. Short-linted plants can be eliminated easily and rapidly from the commercial crop by the adoption of the pedigree culture method.

2. Slight differences in lint length, weight of lint per seed, seed weight, and weight of lint per boll are hereditary, and are maintained from season to season.

3. The yield of Sea Island cotton can be increased by selecting plants possessing certain combinations of morphological characters.

4. Particular attention should be paid to weight of lint per seed, and seed weight. Weight of lint per seed is correlated with weight of lint per boll, and with weight of lint per acre.

5. Types of high seed weight must be grown because the maximum weight of lint per seed can only occur if the seed weight is also at the maximum.

6. There is a strong correlation between parent and mean of progeny in respect of the characters lint length, lint weight, and seed weight. The character of a plant therefore affords some guide to the kind of progeny it will produce, but in general, the inherent worth of a plant can only be judged in terms of the average behaviour of its progeny.

7. Lint length and lint weight are possibly negatively correlated, but there is a need for further investigation of the subject. No strain exists at the present time possessing the combination of long lint (above 55 mm.) and high lint weight (above 55 mg.).

8. The chief danger of pure strain work with Sea Island cotton is that valuable combinations of Mendelian factors may be permanently lost, unless full attention be given throughout the period of selection to all the morphological and physiological characters bearing on yield.

9. The particular combination of Mendelian factors which has given rise to the Montserrat strain of lint weight 60 mg., appears to have been eliminated from the St. Vincent and St. Kitts commercial cottons.

10. The yield of St. Vincent and St. Kitts cottons can undoubtedly be increased by crossing them with the heaviest yielding Montserrat strain, and the whole question of artificial hybridization in relation to cotton breeding is discussed at length.

11. A method of improving Sea Island cotton is set forth which will give practical results in a comparatively short space of time.

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Table I.

MEAN MAXIMUM LENGTH OF LINT.

Frequency Arrays for Montserrat Strains, 1916-1918.

Family.	Year.	Parent.	Lint Length in M.M.												Mean.
			45	46	47	48	49	50	51	52	53	54	55	56	
D1	1916	-						1	3	12	14	4	1		53
D1-4	1917	53							7	9	4				52
D1-4-10 ...	1918	51			2	27	19	2							49
D1-4-14 ...	1918	52				2	10	6	2						49
D1-5	1917	53						1	3	13	2	1			52
D1-5-8 ...	1918	51				1	2	12	5						50
D1-11	1917	52						1	3	13	2	1			52
D1-16	1917	53									9	8	2	1	54
D1-16-7 ...	1918	55							3	13	7	3	1		53
D1-16-19 ...	1918	56					1	-	-	8	8	11	2		53
D1-25	1917	53							10	6	3	-	1		52
D1-26	1917	53							1	11	4				52
D1-30	1917	53							3	13	4				52
D1-30-4 ...	1918	52				1	4	9	6						50
D1-36	1917	51							4	8	5				52
D1-36-7 ...	1918	52				1	9	5	5						50
H9-23	1916						1	2	7	10	15	4			52
H9-23-2 ...	1917	53							7	9	4				52
H9-23-2-1 ...	1918	53	1	-	2	6	3	14	4	1					49
H9-23-2-13 ...	1918	52		3	18	19	10								48
H9-23-2-15 ...	1918	52			5	17	13	13	2						49
H9-23-2-16 ...	1918	53		1	11	12	11	5							48
H9-23-2-17 ...	1918	52		4	9	19	11	4	3						49
H9-23-3 ...	1917	53						2	7	4					51
H9-23-10 ...	1917	53							6	12	2				52

TABLE I.—*Continued.*

MEAN MAXIMUM LENGTH OF LINT.

Frequency Arrays for Montserrat Strains 1916-1918.

Family.	Year.	Parent.	Lint Length in M.M.												Mean.
			45	46	47	48	49	50	51	52	53	54	55	56	
H9-23-11 ...	1917	52						1	8	10	1				52
H9-23-11-7 ..	1918	53				1	10	8	1						50
H9-23-12 ...	1917	54							6	12	2				52
H9-23-12-3 ..	1918	52			1	3	5	7	4						50
H9-23-14 ...	1917	53						1	12	5					51
H9-23-14-1 ...	1918	51			5	10	5								48
H9-23-14-3 ...	1918	51				11	9								49
H9-23-18 ...	1917	52						5	12	3					51
H9-23-23 ...	1917	53						7	10	3					51
H9-23-27 ...	1917	52						4	10	6					51
H9-Th ...	1916								1	12	12	8	4	2	53
H9-Th-1 ..	1917	53							2	13	5				52
H9-Th-1-1 ..	1918	52				1	8	9	2						50
H9-Th-1-4 ...	1918	53			10	19	18	3							48
H9-Th-5 ...	1917	54							3	16	1				52
H9-Th-5-15 ..	1918	51				5	13	1	1						49
H9-Th-10 ...	1917	53							4	9	6	1			52
H9-Th-10-4 ...	1918	54				1	6	4	4	2	3				51
H9-Th-11 ...	1917	53							13	7					51
H9-Th-22 ...	1917	52						1	11	7	1				51
H9-Th-22-4 ...	1918	51			3	10	7								48
H9-Th-36 ...	1917	52						1	3	13	3				52
H9-Th-36-9 ...	1918	52				7	8	5							49
H9-Th-37 ...	1917	54							2	10	8				52
H9-Th-37-5 ...	1918	52			2	6	10	2							49

TABLE II.

MEAN MAXIMUM LENGTH OF LINT.

Frequency Arrays for St. Vincent Strains, 1917-18.

Family.	Year.	Parent.	Lint Length in Mm.														Mean.
			43	44	45	46	47	48	49	50	51	52	53	54	55	56	
BS1-33 ...	1917	–	2	2	2	3	3	2	–								46
BS1-53 ...	1917	–		1	2	1	1	4	6	4	2						48
BS1-53-7 ...	1918	50				1	11	12	13	6	1						48
V1-9-7 ...	1917	–								5	3	3	2	1			51
V1-9-19 ..	1917	–			1	–	–	3	5	3	3						49
V1-9-22 ..	1917	–					1	2	3	5	8	5	2				51
V1-9-22-18 ...	1918	50				1	6	6	10	9	1						49
V1-9-27 ...	1917	–					1	3	2	5	6	2					50
V1-9-35 ...	1917	–						1	3	8	6	2					50
V1-9-37 ...	1917	–									4	5	6	2	1		53
V1-9-37-5 ...	1917	53						7	13	11	10	–	1				50
V3-32-3 ...	1917	–							1	4	–	3	6	6	1		52
V3-32-3-1 ...	1918	52						6	–	2	1						49
V5-56-33 ...	1917	–		1	–	1	1	2	2	5	–	1	–	1			49
V5-61-34 ...	1917	–			2	–	1	4	1	4							48
V5-61-18 ..	1917	–							2	1	7	7	11	8	1	1	53
V5-61-24 ...	1917	–				1	–	6	5	16	6	9	3				50
V5-61-24-17 ...	1918	50				1	3	7	10	9	3	2	1				49
V5-61-28 ...	1917	–							1	–	6	5	8	–	1		52
V13-1-18 ...	1917	–					1	3	3	1	1	–	1				49
V13-1-20 ...	1917	–					1	–	2	9	7	6	5	1			51
V13-1-20-30 ...	1918	–							1	10	1						50

Table III.

MEAN WEIGHT OF LINT PER SEED.

Frequency Arrays of Montserrat Strains, 1916-18.

Family.	Year	Parent.	Weight of Lint per seed in Mg.														Mean.
			29	32	35	38	41	44	47	50	53	56	59	62	65	68	
D1	1916			1	1	9	9	9	5	1							42
D1-4	1917	44					1	6	9	2							45
D1-4-10 ...	1918	48					4	18	16	8	3	1					46
D1-4-11 ...	1918	54					1	5	7	2							45
D1-5	1917	49				3	6	7	4								43
D1-5-8 ...	1918	45		1	1	1	2	10	5								43
D1-11 ...	1917	42				2	6	7	1								41
D1-16 ...	1917	57	1	6	6	3											33
D1-16-7 ...	1918	31	2	5	9	9	2										35
D1-16-19 ...	1918	51	3	11	3	1	2										31
D1-25 ...	1917	39		4	8	5	3										36
D1-26 ...	1917	45				2	7	5	1								42
D1-30 ...	1917	48		2	5	6	6	1									38
D1-30-4 ...	1918	45				6	11	3									41
D1-36 ...	1917	45			1	4	9	1									40
D1-36-7 ...	1918	41			2	10	6	2									39
H9-23 ...	1916	50			1	–	–	4	8	5	11	7	–	2			51
H9-23-2 ...	1917	56							1	2	6	5	4	1	–		156
H9-23-2-1 ...	1918	68					5	2	4	12	4	3					49
H9-23-2-13 ...	1918	60								2	1	8	13	18	7		160
H9-23-2-15 ...	1918	61							1	3	10	22	11	3			56
H9-23-2-16 ...	1918	59								4	13	20	1	1			55
H9-23-2-17 ...	1918	62				1	–	2	7	10	11	14	2				52
H9-23-3 ...	1917	61				–			1	4	3	3					52
H9-23-10 ...	1917	54						6	3	8	3						48

TABLE III.—(*Concluded*).

MEAN WEIGHT OF LINT PER SEED.

Frequency Arrays of Montserrat Strains, 1916-18.

Family.	Year.	Parent.	Weight of Lint per seed in Mg.														Mean.
			29	32	35	38	41	44	47	50	53	56	59	62	65	68	
H9-23-11 ...	1917	56						2	4	9	4	-	1				50
H9-23-11-7 ...	1918	52						1	1	10	2	5	1				52
H9-23-12 ...	1917	52					1	3	8	7	1						45
H9-23-12-3 ...	1918	51						2	4	6	7	1					47
H9-23-14 ...	1917	48					1	2	7	5	2	1					50
H9-23-14-1 ...	1918	53						1	1	6	3	7	1	1			50
H9-23-14-3 ...	1918	50								6	4	7	3				51
H9-23-18 ...	1917	54						2	4	5	6	2	1				48
H9-23-23 ...	1917	51					2	3	6	7	1	1					45
H9-23-27 ...	1917	52						3	3	7	2	5					47
H9-Th ...	1916						4	2	7	7	11	3	3	1			48
H9-Th-1 ..	1917	50						1	1	5	7	5	-	1			50
H9-Th-1-1 ...	1918	58								2	5	7	5	1			53
H9-Th-1-4 ...	1918	53						2	2	11	8	13	11	3			51
H9-Th-5 ...	1917	51					1	3	6	6	3	1					46
H9-Th-5-15 ..	1918	50						5	6	3	5	1					45
H9-Th-10 ...	1917	37				1	5	8	3	3							41
H9-Th-10-4 ...	1918	36			1	5	7	5	1	1							38
H9-Th-11 ...	1917	50						8	8	2	2						44
H9-Th-22 ...	1917	51						4	3	6	6	1					47
H9-Th-22-4 ...	1918	52							4	10	5	-	1				48
H9-Th-36 ...	1917	54							2	8	7	2					48
H9-Th-36-9 ...	1918	52						1	1	3	8	5	1				50
H9-Th-37 ...	1917	53							2	3	6	7	2				51
H9-Th-37-5 ...	1918	54							1	6	8	4	-	1			50

Table IV.

MEAN WEIGHT OF LINT PER SEED.

Frequency Arrays for St. Vincent Strains 1916-18.

Family.	Year.	Parent.	23	26	29	32	35	38	41	44	47	50	53	56	59	Mean.
BS1	1916	43			2	–	–	1	–	1						35
BS1-33 ...	1917	29				2	4	–	1							35
BS1-53 ...	1917	30		1	1	3	6	4	1							35
BS1-53-7 ...	1918	42	1	–	–	9	21	14	1							35
BS5	1916	35			3	4	17	6								35
BS6	1916	36			3	6	6	6								34
V1-9	1916	42							1	3	3	3				46
V1-9-7 ...	1917	43						3	2	5	4					43
V1-9-19 ..	1917	51								2	3	6	1			49
V1-9-22 ...	1917	47							1	8	4	6	2			47
V1-9-22-18 ...	1918	55							3	15	16	5	1			46
V1-9-27 ...	1917	43					1	3	3	7	2	1	1			42
V1-9-35 ...	1917	49						1	3	3	7	2	1			46
V1-9-37 ...	1917	46						1	2	4	6	2	1			46
V1-9-37-5 ...	1918	–						1	3	19	7	3				45
V3-32 ...	1916	45						4	4	4	7					43
V3-32-3 ...	1917	47								1	7	3	4	2		50
V3-32-3-1 ..	1918	56									1	7	1			50
V5-56 ..	1916	42					1	3	1	1	1	1				41
V5-56-33 ...	1917	–							2	3	2	4				46
V5-56-34 ...	1917	–							1	3	5	3				47
V5-61 ...	1916	48					2	1	5	4	5					43
V5-61-18 ..	1917	–					1	2	6	4	8					43
V5-61-24 ...	1917	47							5	10	11	4	2			46
V5-61-24-17 ...	1918	53							6	18	12	1				45
V5-61-28 ...	1917	–				1	1	–	2	7	3	1	1	–	1	42
V13-1 ...	1916	44						3	8	6	1	1	1			43
V13-1-18 ...	1917	52								4	2	3	1			47
V13-1-20 ...	1917	51				2	–	1	3	8	5	5	1			45
V13-1-20-30 ...	1918	–							7	13	1	–	1			44

Table V.

MEAN SEED WEIGHT.

Frequency Arrays of Montserrat Strains, 1916-18.

Family.	Year.	Parent.	Mean Seed Weight in Mg.																					Mean.
			88	93	98	103	108	113	118	123	128	133	138	143	148	153	158	163	168	173				
D1	1916							3	2	2	12	6	7	1	2									130
D1-4 ...	1917	139				1	–	2	3	5	2	5	1											125
D1-4-10 ...	1918	118			4	5	5	16	8	10	2													114
D1-4-14 ...	1918	132					1	6	3	3	1	2	1											121
D1-5 ...	1917	122					6	7	2	3	1													116
D1-5-8 ...	1918	113				2	–	2	5	5	3	3												121
D1-11 ...	1917	127					6	7	2	3	1	–	1											116
D1-16 ...	1917	113	1	2	3	4	8	2																104
D1-16-7 ...	1918	96	1	5	1	9	3	6	1	–	1													105
D1-16-19 ...	1918	107	2	7	14	4	3	2	1															99
D1-25 ...	1917	115		1	3	2	3	6	5															109
D1-26 ...	1917	131					1	5	7	1	1													117
D1-30 .	1917	127		1	4	6	3	2	3	1														107
D1-30-4 ...	1918	119		1	1	5	6	6	1															108
D1-36 ...	1917	142				4	1	5	1	3	1													113
D1-36-7 ...	1918	105				2	9	6	2	1														101
H9-23 ...	1916							1	2	5	4	8	4	5	4	2	2	1						136
H9-23-2 ...	1917	146							1	3	4	3	4	5										133
H9-23-2-1	1918	136			1	1	2	3	5	6	5	–	1	2	1									120
H9-23-2-13	1918	136						2	1	8	9	12	7	7	4									133
H9-23-2-15	1918	143						1	2	6	10	11	9	5	2	1								133
H9-23-2-16	1918	143						1	2	9	13	3	8	3	1									130
H9-23-2-17	1918	142					1	10	19	12	3	5												120
H9-23-3 ...	1917	152							2	1	3	3	1											128
H9-23-10 ...	1917	144					2	3	8	5	1	–	1											119

TABLE V.—(*Concluded.*)

MEAN SEED WEIGHT.

Frequency Arrays of Montserrat Strains, 1916-18.

Family.	Year.	Parent.	Mean Seed Weight in Mg.																			Mean.
			88	93	98	103	108	113	118	123	128	133	138	143	148	153	158	163	168	173		
H9-23-11 ...	1917	118						8	7	2	2	1										118
H9-23-11-7	1918	119					1	2	8	5	2	2										120
H9-23-12 ...	1917	138				2	1	8	5	1	2	–	1									116
H9-23-12-3	1918	136			1	1	3	7	6	2												114
H9-23-14 ...	1917	130				2	4	4	3	3	1	1										115
H9-23-14-1	1918	123				3	2	8	3	3	1											114
H9-23-14-3	1918	123				1	4	1	7	3	4											118
H9-23-18 ..	1917	135			1	1	1	5	6	2	1	2	1									118
H9-23-23 ...	1917	131			2	2	5	3	3	1	3	–	1									114
H9-23-27 ..	1917					4	2	5	2	2	3	1	–	–	–	1						117
H9-Th ...	1916						1	1	–	1	4	7	1	9	5	1	4	2	–	2		142
H9-Th-1 ...	1917	130							2	7	4	4	1	2								128
H9-Th-1-1	1918	142						2	4	5	4	4	–	1								125
H9-Th-1-4	1918	131					2	6	8	11	7	3	3									123
H9-Th-5 ...	1917	147				1	–	2	2	3	2	8	2									127
H9-Th-5-15	1918	126				1	2	6	4	3	3	–	1									118
H9-Th-10 ...	1917	131					3	7	3	4	1	–	2									118
H9-Th-10-4	1918	123						7	4	4	3	1	1									121
H9-Th-11 ...	1917	143						2	3	6	2	5	2									126
H9-Th-22 ..	1917	142					1	1	2	4	3	6	2	1								128
H9-Th-22-4	1918	134					2	4	5	5	3	1										120
H9-Th-36 ...	1917	156								1	3	5	4	3	2							136
H9-Th-36-9	1918	131						1	1	3	3	5	4	3								132
H9-Th-37 ...	1917	143								1	4	4	5	4	2							136
H9-Th-37-5	1918	136						1	2	5	2	6	4									129

TABLE VI.

MEAN SEED WEIGHT.

Frequency Arrays for St. Vincent Strains, 1916-18.

Family.	Year.	Parent.	Mean Seed Wt. in Mg.												Mean.
			93	98	103	108	113	118	123	128	133	138	143	148	
BS1	1916	–						1	1	1	1	1			128
BS1-33 ...	1917	–						4	1	–	2	1			125
BS1-53 ..	1917	–						4	5	2	4	1	1	1	128
BS1-53-7 ...	1918	125	1	2	5	11	11	6	6	3	–	1			113
BS5	1916	117		1	4	10	4	2	7	2	1	1			115
BS6	1916	116		1	2	9	1	2	3	2	1				113
V1-9	1916	111								1	2	4	2	1	138
V1-9-7 ...	1917	132				1	3	4	2	4					120
V1-9-19 ..	1917	132				1	1	4	2	4					121
V1-9-22 ...	1917	136						7	2	4	4	4	1		128
V1-9-22-18 ...	1918	136				1	3	6	14	7	10				124
V1-9-27 ...	1917	142			1	–	1	1	6	3	2	3			126
V1-9-35 ...	1917	138						4	2	2	4	4	1		129
V1-9-37 ...	1917	137						1	3	4	5	2	1		130
V1-9-37-5 ...	1918	–				1	4	7	10	6	4	1			123
V3-32 ...	1916	129		1	1	2	4	5	2	4					117
V3-32-3 ...	1917	124		2	–	–	7	4	2	1					115
V3-32-3-1 ...	1918	121					2	2	4	1					120
V5-56 ..	1916	103						2	3	1	–	1			124
V5-56-33 ...	1917	127				1	1	1	1	4	3				125
V5-56-34 ...	1917	140					2	1	2	3	3	1			126
V5-61 ...	1916	120			2	3	3	4	5	1					116
V5-61-18 ..	1917	116				2	7	10	1	1					116
V5-61-24 ...	1917	119			2	3	5	9	9	5					118
V5-61-24-17 ...	1918	114	1	–	6	16	12	3							109
V5-61-28 ...	1917	121			1	1	5	7	2	1					116
V13-1 ...	1916	–			2	2	–	7	4	3	1	–	1		120
V13-1-18 ...	1917	143									6	4	1		136
V13-1-20 ...	1917	132					1	–	5	10	6	2	2		129
V13-1-20-30 ...	1918	126					1	5	8	5	2	1			124

TABLE VII.

Showing Number of Bolls to 1 lb. of Seed Cotton, Weight of Seed Cotton per Boll, Weight of Lint per Boll, and Weight of Lint per Acre, in the Montserrat Strains of 1917-18.

Family.	Year.	Bolls to 1 lb.	Seed cotton per Boll, gms	Lint per boll, gms.	Lint per acre, lbs.
D1-4	1917	144	3·15	0·85	445
D1-4-10	1918	146	3·11	0·90	527
D1-4-14	1918	145	3·13	1·09	660
D1-5	1917	160	2·84	0·77	427
D1-5-8	1918	153	2·97	0·78	563
D1-11	1917	177	2·56	0·67	465
D1-16	1917	188	2·41	0·59	410
D1-16-7	1918	160	2·84	0·74	563
D1-16-19	1918	192	2·37	0·61	461
D1-25	1917	180	2·52	0·65	429
D1-26	1917	160	2·84	0·75	452
D1-30	1917	174	2·61	0·68	454
D1-30-4	1918	170	2·67	0·73	512
D1-36	1917	166	2·80	0·73	538
D26	1917	142	3·20	0·96	645
H9-23-2	1917	119	3·82	1·12	727
H9-23-2-1 ...	1918	138	3·29	0·95	544
H9-23-2-13 ..	1918	116	3·91	1·20	774
H9-23-2-15 ...	1918	113	4·02	1·19	647
H9-23-2-16 ...	1918	119	3·82	1·13	–
H9-23-2-17 ...	1918	134	3·39	1·02	584
H9-23-3	1917	129	3·52	1·00	479
H9-23-10	1917	130	3·49	1·02	488
H9-23-11	1917	129	3·52	1·03	529
H9-23-11-7 ...	1918	128	3·55	1·06	643

TABLE VII.—(*Concluded.*)
Showing Number of Bolls to 1 lb. of Seed Cotton, Weight of Seed Cotton per Boll, Weight of Lint per Boll, and Weight of Lint per Acre, in the Montserrat Strains of 1917-18.

Family.	Year.	Bolls to 1 lb.	Seed cotton per boll, gms.	Lint per boll, gms.	Lint per acre, lb.
H9-23-12	1917	137	3·31	0·93	504
H9-23-12-3 ...	1918	132	3·44	1·01	537
H9-23-14	1917	138	3·29	0·92	651
H9-23-14-1 ...	1918	124	3·67	1·12	781
H9-23-14-3 ...	1918	136	3·34	1·01	628
H9-23-18	1917	147	3·09	0·89	524
H9-23-23	1917	145	3·13	0·89	467
H9-23-27	1917	149	3·20	0·92	427
H9-Th-1	1917	123	3·70	1·02	514
H9-Th-1-1 ...	1918	123	3·70	1·09	639
H9-Th-1-4 ..	1918	129	3·52	1·05	651
H9-Th-5	1917	135	3·36	0·88	508
H9-Th-5-15 ...	1918	129	3·52	0·98	609
H9-Th-10	1917	141	3·22	0·83	527
H9-Th-10-4 ...	1918	136	3·34	0·81	468
H9-Th-11	1917	132	3·44	0·89	442
H9-Th-22	1917	122	3·72	0·99	459
H9-Th-22-4 ...	1918	128	3·55	1·01	595
H9-Th-36	1917	119	3·82	1·00	529
H9-Th-36-9 ...	1918	115	3·95	1·09	660
H9-Th-37	1917	124	3·67	0·99	503
H9-Th-37-5 ...	1918	127	3·58	1·00	641
St. K. 14	1917	157	2·89	0·89	597
St K. 18	1917	159	2·86	0·79	462

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